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Agricultural Policy, Technology Adoption, and Farm Structure

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ABSTRACT

The linkages among farm policy instruments, technological introduction and adoption, and the structure of agriculture are illustrated in an economic model. The model shows that policy merely delays, but cannot prevent, the consequences of technological advance. New technology permits fewer farms to produce more output at lower cost, and ultimately about the same per-farm profit, than possible under the old technology. Producer-preserving policies encourage more farms to adopt the new technology than the market will support and impose adjustment costs as these farms exit after switching technologies rather than directly leaving the sector. Exit annuity payments could facilitate the adjustment process at less than one-third the cost of current program instruments, and benefit both the exiting farmers and those who remain in business.

KEYWORDS: Technology, diffusion, policy, simulation, structure, adjustments.

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INTRODUCTION

Today's farm programs were presented as "temporary" solutions to political problems whose rallying cries were, "Save the family farm!" As technology expanded supply faster than consumer numbers and incomes expanded demand, prices fell. Farm income fell as prices fell. During the more than half-century of farm program operations, farm numbers fell from 6.8 million to 2.2 million, farm employment dropped from more than 10 million to 3.5 million, and farm employment declined from more than 26 percent to merely 3 percent of national employment.

Farm commodity programs have focused on the prices, production, and acreage symptomatic of the problems, rather than on technology and the structural issues at the root of the problems. Analysis of the structural effects of such programs has emphasized the static distributional question "Who received how much?," rather than the dynamic issues of "How many farms were 'saved'?," "Do programs encourage entry, as well as discourage exit?," "How rapidly do farms adjust to new technologies?," "What happens when farms don't adjust?," and "What happens to the farmers displaced, or the resources freed up, by the new technology?" "Can the nonfarm economy absorb the displaced farmers?"

When "the market works," the adjustments, if not "instantaneous," are "easy" and the disruptions are "minimal," and the discussion ends here. If it doesn't, the issues boil down to "What constitutes disruption?," "What are the farmers' off-farm opportunities?," and "Do they vary across the country?" One role for policy would be to ease that adjustment process. This paper examines how various instruments of agricultural policy affect adjustments in a simulated environment.

Over the years, a number of instruments have been designed as "means" directed at the higher "end" of "saving the family farm." Target prices, loan rates, set-asides, paid diversions, conservation reserves, land banks, direct payments, marketing quotas, parity prices, income parity, and others are all part of this set of instrumental means. Despite the legal nuances of difference among them, they fall into one of three categories: product market intervention, input market (primarily acreage) intervention, and direct payments to producers.

The farm program in any year is complicated by the fact that aspects of all three instrumental prototypes are simultaneously at work. Moreover, they act at

cross purposes with each other, offsetting each other's effects. In a sense that will be developed later in this report, the farm programs lock farmers in place, like a "golden handcuff," without affecting their longrun level of income or well-being.

On the other hand, direct payments, like an exit annuity or "golden handshake," to farmers choosing to go out of business will alter the longrun incomes of those remaining in agriculture.[1] That is, factors which change the perceived off-farm income opportunity will change the longrun income realized by farmers. In the 1930s, the construction of the Tennessee Valley Authority dams brought off-farm job opportunities into a region with many low-income farms. In the 1950s and 1960s the interstate highway system provided another adjustment opportunity to farmers. Its construction provided an off-farm opportunity to many farmers who were too young to retire and slow to migrate to other jobs, not knowing how transferable their skills were. Other private-sector opportunities were provided by the migration of manufacturing plants into the South.

To understand the interactions among technology, farm policy, and the structure of the industry, one can retreat from the complex reality into a laboratory that permits experimentation. For an economist, that laboratory is a mathematical model of the phenomenon.[2] This deductive model makes explicit all the relationships which underlie Cochrane's (1957) "technological treadmill."[3] The

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[1] The concept and terminology of a "golden handshake" was suggested by Neil Conklin, chief of the agriculture branch, OMB, formerly of ERS. Daniel Price (vol. 1, p. 18) recommended a program of assisting people moving from rural to urban areas (patterned after the immigrant aid societies), but did not recognize that it would change the incomes of both migrants and nonmigrants. He did not recommend advertising such a program in rural areas, lest it "unwittingly" encourage outmigration from rural areas.

[2] The framework evolved from work reported in Teigen and others (1985). A preliminary version is described in Teigen (1986). The model in this analysis is deductive and hypothetical, rather than inductive and empirical. A number of empirically meaningful concepts in the model are not empirically observable.

[3] Cochrane's 1965 summary of the "treadmill hypothesis" states: "The innovators reap the gains of technological advance during the early phases of adoption, but after the improved technology has become industry-wide, the gains to innovators and all other farmers are eroded away either through falling product prices or rising land prices or a combination of the two, and in the long run the specific income gains to farmers are wiped out and farmers are back where they started -- in a no-profit position. In this sense, technological advance puts farmers on a treadmill" (p. 66).

Cochrane's observation on land price adjustments is parameter-dependent. If the acreage response to product price is large enough, the falling product prices overwhelm the input demand shifts due to the new technology and land prices fall. Counterexamples have been constructed to his claim that land prices rise, capitalizing the value of the technology. The simulation model in this paper generated equilibrium land rental rates which exceeded the original levels. Replacing the quadratic production functions in this paper by Cobb-Douglas production functions having the same initial equilibrium

unit for understanding technology is the firm. Adjustments in the markets for inputs and output determine prices and quantity levels. The resulting per-firm profits motivate the entry and exit decisions of marginal farms and govern the rate of technological adoption.

Although the analysis is numerical, the proper inference from it is qualitative. Conclusions based on the structure of the relationships transcend those based on the parameters within the relationships. This discussion emphasizes those structure-based ordinal conclusions, and uses the specific parameter-determined numerical results only as illustrations of the more general point. The model's parameters generally represent the markets faced by the U.S. agricultural sector as a whole, and where available econometric estimates comparable to our assumptions are given. But, many of the parameters are unobservable. For them, hypothetical values were assigned, consistent with the remainder of the model.

DEFINING TERMS

In order to assess the structural consequences of technological change, ambiguity must be removed from a number of terms. This section defines the sense in which production, supply, input demand, and marginal product functions are used in this paper, and distinguishes among three equilibrium concepts. Market equilibrium is distinguished from technological equilibrium, which is distinct from structural equilibrium.

Production function

The production function is the mathematical relationship which determines the firm's transformation of inputs into output. It is the formal embodiment of technology. That is, it represents all that is known about a particular technology. When technology changes, the result is a different production function. For any combination of inputs, however chosen, a unique output is determined by the production function.[4] The production function is strictly a

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values generated one such counterexample (see appendix). Another counterexample, also in the appendix, was generated by a quadratic production function for which the acreage demand elasticity to product price was -0.1.

Nelson and Cochrane's assessment that farm programs caused fewer and larger farms, and more rapid technological adoption, than the free market is contradicted by this analysis. Nelson passively determines the number of farms by dividing land in farms by the average size of farms, which is determined by aggregate capital investment. In this paper, farm numbers and technological adoption are explicitly related to per-firm profits of marginal firms, rather than submerged in aggregate regression equations.

[4] For a nontrivial set of inputs (not necessarily all input combinations), the production function should be positive, increasing, and concave. Concavity generalizes the idea of diminishing marginal productivity. In the case of analytical functions, at every point (x_o) within that nontrivial set, $F(x_o)$ is positive, every element of the gradient of F at (x_o) is positive, and the Hessian (matrix of second derivatives) of F at (x_o) is negative definite. The determinant of the Hessian is called the Jacobian.

firm-level phenomenon. None exists at the market or industry level.[5]

Supply function

At the firm level, the supply function relates the quantity of output produced to the prices of inputs and the output price. The firm-level supply function reflects both technological and behavioral factors.[6] That is, when firms behave as though they maximize their profits, the supply function can be derived from the production function and its derivatives. The supply function for the industry-level of output is the summation of the individual firm-level supply functions. This aggregation process assumes that all producers experience the same prices of output and inputs (or prices which are rigidly linked to those experienced by all other producers).

Input demand function

At the firm level, the input demand function is jointly determined with the firm's supply function, and relates the level of each input to the prices of all inputs and the output price. The firm-level input demand function reflects both technological and behavioral factors, in the same manner as the firm-level supply function. The input demand function is a "vector-valued" function; that is, for each combination of relative input prices in its domain, a unique vector of input levels is determined. The market-level input demand function is the sum of the firm-level input demand functions, which assumes that all firms experience the same (or rigidly linked) prices as all other firms.

Marginal product function

The marginal product function is derived from the production function. The marginal product function is identical to the mathematical notion of the "gradient" of the production function. It is a vector-valued function whose individual coordinate functions are the partial derivatives of the production function. The domain of the marginal product function is the set of input levels permissible in the production function. The inverse of the marginal product function is the input demand function, in the sense that the composite function[7] consisting of the marginal product composed with the input demand is the identity function.

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[5] So-called "aggregate production functions" imperfectly reflect the technology used by firms within the industry (Theil).

[6] Behavioral factors include the personalized objective function and constraints which determine the reaction of the firm's decisionmaker. By definition, all the technological factors are represented in the firm's production function.

[7] Let f be a function whose domain is a set S, and g be a function whose domain is a set D. If for every x in D, g(x) is in the set S, a composite function (f composed with g) can be defined. The composed function, denoted $f \circ g\,(x)$, is defined as $f(g(x))$ for every x in the set D. If f and g are both continuous, then $f \circ g$ is continuous. See Buck, p. 62, Royden, p. 9, or Takayama, p. 3.

Market equilibrium

Market equilibrium occurs at price levels that equate the quantity offered by all suppliers with the quantity demanded by all customers. The number (and size distribution) of buyers and sellers operating within the market does not change during this equilibration process. Market equilibrium is a specific form of the economist's "shortrun" equilibrium.

Technological equilibrium

Technological equilibrium occurs when there is no incentive for firms to use a different technology of production.[8] Although several technologies may be used within the industry, each firm uses only one technology (that is, a unique production function). By comparing its profit with that of those using other technologies and considering the costs of the changeover, a firm can determine the incentive for changing technique. The larger the incentive to change, the more rapid the changeover. But, complete adoption of the most profitable technology is not instantaneous. At each point in time, the distribution of firms refers to the number employing each of the available technologies.

Structural equilibrium

Structural equilibrium occurs when there is no incentive for the number (or distribution) of firms in the industry to change. Structural equilibrium presumes market and technological equilibrium, but not vice versa. Structural equilibrium is a longrun state in which all the forces motivating change are balanced.[9] Operationally, when the profits (gross margin) of the most profitable firms lie within a closed interval, the equilibrium is established. The upper bound of the interval is the entry threshold (higher profits stimulate entry), and the lower bound is the exit threshold (lower profits motivate exit). These entry and exit thresholds are known only to firms either not yet, or no longer, in the industry, thereby complicating statistical observation and estimation.[10]

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[8] Technological equilibrium was the subject of Griliches' analysis of hybrid corn and Kislev's study of the "innovation cycle." Most studies of technological adoption do not examine the structural changes which occur after the industry has completely adopted the technology. In the 5 years (1959-64) after hybrid corn achieved its technological equilibrium, more than 1 million farms ceased corn production (half of the number of farms harvesting corn in 1959).

[9] The relative stability of the number of farms in the United States during 1900-45, in contrast with the substantial declines during 1945-70, is consistent with structural equilibrium. The homogeneity of size and commodity mix among farms, as well as their regional distribution, are other attributes of structural equilibrium. Kislev and Peterson (1982) did not explain changes in farm numbers.

[10] Considerable information about the thresholds of marginal farms could be obtained by intensive efforts to locate operators of farms which ceased operation between successive sample periods for USDA surveys, or between successive agricultural censuses. A similar followup could be undertaken with

The entry and exit thresholds represent the opportunity costs of the marginal entrant or marginal farmer. When the gross margin (profits) equal those opportunity costs, the firm's total revenue will equal the total compensation to the variable factors plus the (noncontractual) payments to owned factors, exhausting the total product. Under Euler's theorem, product exhaustion will occur if the production function is homogeneous of degree one in all factors. The boundary condition for structural equilibrium shows how product exhaustion occurs for nonhomogeneous production functions.

THE MODEL

The industry

The initial state of the industry is assumed to be one of structural equilibrium. The product and input markets are in equilibrium. A single technology of production is being employed by all farms in the industry. The initial profit level was between the opportunity thresholds of potential entrants and potential exits.

For the sake of numerical convenience, there are 100 farms in the industry each of which produces 1,000 units of output each of which sells for a price of $1. Three inputs are used in production: hired labor, fertilizer, and land. Each farm initially uses 1 unit of each input to produce the 1,000 units of original production. The price of each unit of labor, fertilizer, and land is $200, $100, and $70. The initial profit, $630 per farm, was between the entry and exit thresholds.

The technology of production is represented by a quadratic production function. For each vector of inputs x, $F(x) = a + d'x + .5 * x'Hx$ determines the level of output. The vector d generally has positive elements, and, to ensure concavity, the matrix H is negative definite. Concavity is the necessary second-order condition to ensure that a profit-maximizing point has been reached.

Assuming profit maximization, inputs are chosen so that $F'(x) = w/p$, where w is the vector of input prices, and p is the price of the output.[11] This solution

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operators who have just entered farming.

Studies of rural-urban migration show that migrants' incomes before the move were less than nonmigrants' and that their post-move incomes were greater than nonmigrants' (see, for example, Price, and Hamilton and others).

[11] F'(x) is the gradient of the function F, evaluated at x. The gradient is the vector function whose coordinate functions are the respective partial derivatives of F.

Although the model is deterministic, something should be said about the response-inducing prices. The behavior is based on "rational expectations," in the sense of Muth, where the prices of both output and inputs are those which "clear the market," based on the number of firms, the distribution among technological cohorts, the input supply and product demand functions, and the

results in the input demand function. Based on the quadratic production function, $x(w/p) = -H^{-1}d + H^{-1}(w/p)$ is the form of the firm-level input demand function. Bear in mind that x, d, w, and $-H^{-1}d$ are vectors, rather than real numbers. Because H is negative definite, H^{-1} also is negative definite and its diagonal elements are negative.[12]

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production functions of firms in each of the technological cohorts.

The (input demand and product supply) response functions [whose domain is a set of n-vectors of price ratios (w/p)] are derived asssuming prices are exogenous to the firms. When this year's market-clearing prices are substituted into the response functions, the firm's quantities of inputs and output are determined.

[12] The model's parameters were computed so that the functions would possess preset elasticities at the original equilibrium point. In view of the symmetry of H^{-1}, the own-price and output price elasticities of input demand and the (price, quantity) point at which they are evaluated are sufficient to specify the six values in H^{-1}. If H^{-1} is negative semi-definite, an upper triangular matrix U can be determined such that $H^{-1} = -U'U$. The absence of such a matrix (U) implies that the system defined by those elasticities is not concave; that is, does not have the proper slope and curvature at all possible price levels.

The own-price elasticity of input demand at the original equilibrium is -1.1 for labor, -1.0 for fertilizer, and -0.92 for land. The output-price elasticity of demand initially is 0.89 for labor, 0.93 for fertilizer, and -0.78 for land. The negative output-price elasticity of land demand is consistent with the more intensive use of (smaller quantities of) land in higher valued commodity production (for example, calves vs. fed cattle, wheat vs. corn, grain vs. strawberries, houses vs. office buildings).

The exact parameters of H^{-1} are as follows:

-.0055236	-.0016836	+.00541756
-.0016836	-.0103236	+.00621355
+.00541756	+.00621355	-.0131527

The same matrix of coefficients is used to represent the new technology, but with higher (lower) levels of use, the elasticities would be smaller (larger) in absolute value.

By way of comparison, Binswanger (p. 239) estimated a cost function for agriculture which implied own-price elasticities of input demand which were -0.91 for labor, -0.95 for fertilizer, and -0.34 for land. Binswanger's approach did not permit estimation of the output-price elasticity of input demand. Binswanger used observations for 39 States in the Census years 1949, 1954, 1959, and 1964. The number of U.S. farms was 5.4 million in 1950 and 3.2 million in 1964, compared with about 2.2 million farms today. The effect of changing farm numbers would have to be purged from his estimates to directly correspond to the elasticities in my model. A section of the appendix analyzes scenarios using parameters derived from Binswanger's own-price elasticities, coupled with output-price elasticities of 1.0 for labor, 1.25 for fertilizer, and -0.1 for land.

The supply function is a composed function, defined for vectors of relative prices, in which the input demand function is "substituted into" the production function. In algebraic terms, the firm-level supply function[13] derived from the quadratic production function is $S(w/p) = (a - .5* d'H^{-1}d) + .5* w'H^{-1}w/p^2$. The intercept, $(a - .5* d'H^{-1}d)$, is the real number equal to the maximum value of F.

The maximum value of F is 1,108.647 under the original technology, and occurs when the input vector x' = (1.893861, 1.934142, 0.215824). These numerical values are the intercepts of the firm-level supply and input demand functions. The supply intercept is a measure of the absolute capacity[14] of the firm to produce under that technology, and the ratio of the firm's output to that intercept is a measure of the capacity utilization by that firm.

The output-price elasticity of supply is equal, given this function, to twice the ratio of the unused capacity to the current production:
$(2*(\text{intercept} - \text{supply})/\text{supply}) = (2* ((\text{capacity utilization})^{-1} - 1))$.
Consequently, the output price elasticity in the initial state is 0.217.

Because, in the initial state, all farms use the same technology, the industry supply function and the industry input demand function are simply the product of the number of farms and the farm-level functions.

Change in its technology

The technology of the industry changes whenever a new production function is available to the farms in that industry. Technological change is discrete and generally not neutral.[15] The new production function may have the same domain

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[13] The interested reader can verify that the supply function is homogeneous of degree zero in all prices, and the per-firm profit is homoegenous of degree one. That is, if w and p are multiplied by a factor k, the quantity supplied by the firm would be unchanged and its profit would be multiplied by k.

[14] The absolute capacity is the maximum output attainable within the specified time period, regardless of price or cost considerations. It is an asymptote of the supply function in the quantity dimension.

[15] Economic texts have devoted substantial discussion to several versions of "neutral technical progress." Empirical studies have focused on the nonneutralness of technological change. See Kislev and Peterson, Seckler and Schmitz, for examples.

Hicks-neutral progress occurs when the new production function is proportional to the old function. Harrod-neutral change is labor-augmenting, in the sense that one unit of today's labor is equivalent to more than one unit of yesterday's labor, and an invariant function relates output to the quality-adjusted labor and capital however measured. Solow-neutral change is capital-augmenting in the same sense that Harrod-neutral is labor-augmenting (Allen). Solow and Harrod would argue that the original function in the unadjusted inputs is misspecified, and with appropriate measurement of inputs there is but one production function and no change in the sense introduced here.

of inputs as the old, or be defined on a larger set containing inputs not previously available or used by the industry. The variation in technology is the difference between the new production function and the old production function, defined on the union of the domains of the two functions.

The variation in technology examined in this simulation is a linear function of the original inputs, passing through the origin. In other words, the new production function has the same intercept and Hessian as the old, but the linear terms have different coefficients (fig. 1). The marginal product of labor is decreased, while the marginal product of land and fertilizer are increased.[16] The production function's linear parameters are perturbed by (-150, +350, +100) for labor, fertilizer, and land, respectively.[17]

Working the new technology through the profit-maximizing process results in farm-level product supply and input demand functions which are parallel to those under the old technology (fig. 2). Because the Hessian of the production function is not changed, the price response coefficients in the input demand and

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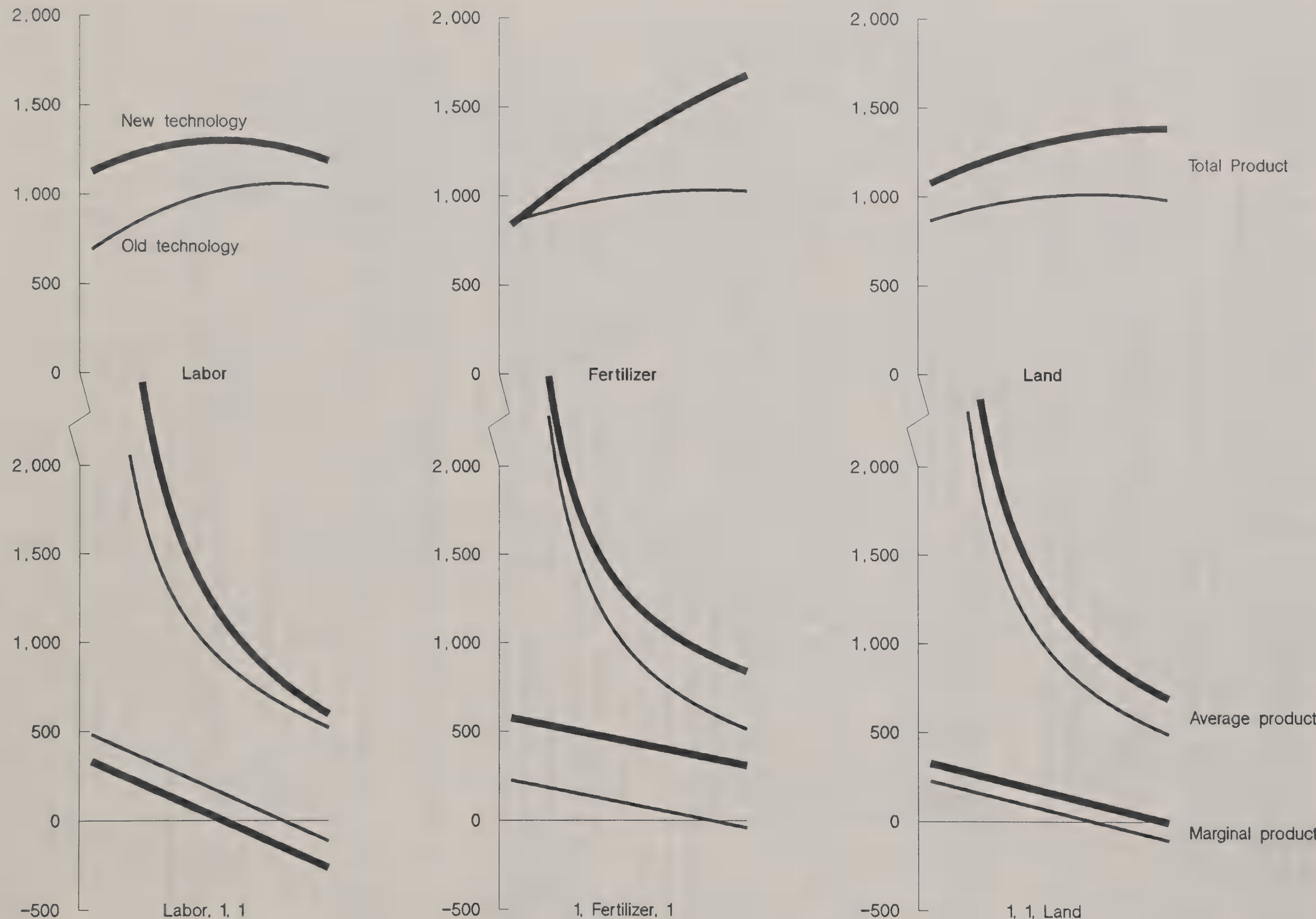
Technical change in the sense of Solow or Harrod is mathematically equivalent to constructing a composite function, involving the original production function and a linear function of the original inputs, given by Ax where A is a diagonal matrix. If the production function is homogeneous of degree one, Hicks-neutral change can be represented by a similar change of variables, where all of the diagonal elements of A are the same number. In Solow- and Harrod-neutral change, all the diagonal elements are equal to 1 except the element for capital or labor. When the diagonal element of A exceeds 1, that input is "saved," or displaced by the new technology. Harrod- or Solow-neutral technical change in a quadratic function would change the input demand function and the price response coefficients of product supply, but would leave the maximum production level (supply intercept) unchanged. Hicks-neutral change in a quadratic production function (which cannot be homogeneous) would change the supply function and the price-response coefficients of input demand, but would leave the input demand intercepts unchanged.

[16] The mechanical tomato harvester was a technology that had these characteristics. It reduced the marginal product of labor at the previous level of employment. In addition to breeding varieties whose skins were able to withstand the mechanical picker, scientists were able to breed in traits of higher yields and greater fertilizer response. See for example, Rasmussen, Webb and Bruce, Seckler and Schmitz, and others.

[17] The initial input demand elasticities imply that the quadratic production function, given by $F(x) = a + d'x + (1/2)\, x'Hx$, has the following parameters: $a = 50.6$ under both technologies, $d' = (697.6, 358.3, 473.0)$ under the old technology, while $d' = (547.6, 708.3, 573.0)$ under the new technology, and the elements of H under both technologies are:

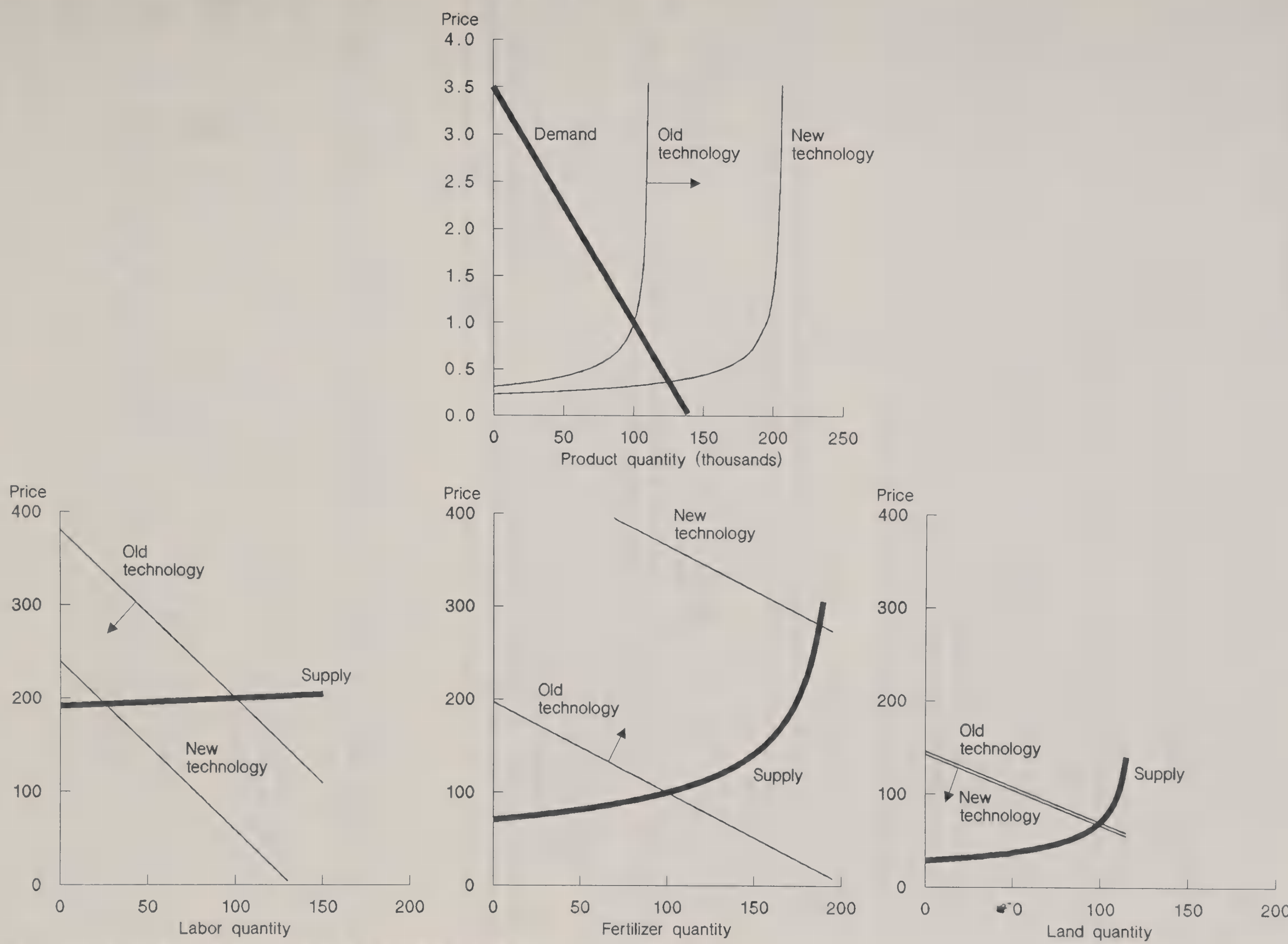
$$\begin{matrix} -313.6 & -37.2 & -146.8 \\ -37.2 & -139.8 & -81.4 \\ -146.8 & -81.4 & -174.9 \end{matrix}$$

Figure 1
Shifts in input-product relationships*



* The production function is defined for orderd triples of labor, fertilizer, and land. The curves drawn with the axis labeled (1, 1, land) show the response of total, average, and marginal product of land to the land input when labor and fertilizer are held constant at 1 unit each. A similar interpretation pertains to the other curves. Each quadrant assumes all other quantities remain at original levels.

Figure 2
Market supply and input demand effects of technological change*



* Each quandrant assumes all other prices and the number of firms remain at original levels.

product supply functions are not affected. Only the intercepts of those functions changed as a result of the new technology.[18]

At every level of prices, the new technology farms will produce 950.078 units more output, using 0.781028 units less labor, 2.739372 units more fertilizer, and 0.046836 units less land, than old-tech farms. Under the new technology, a maximum of 2,058.725 units of output could be produced by employing 1.112833 units of hired labor, 4.673514 units of fertilizer, and 0.168988 units of land. At the original price levels, the supply elasticity of new-tech firms is 0.111 with respect to the output price.

The change in technology is distinct from the adoption of the new technology and its diffusion throughout the industry. Farms will adopt the new technology if there is enough incentive (usually in the form of added profits, net of change-over costs) to do so. Diffusion is the time-pattern of adoption of the technology. The diffusion process describes the transient adjustments between the original equilibrium and the final equilibrium under the new technology. The next section describes the diffusion process as one aspect of structural change.

Change in its structure

The structure of the industry changes whenever the number of farms in the industry changes or the distribution of farms employing the different technologies changes. The closed interval [**bestopp, entry**] defines the equilibrium profit condition. That is, when the most profitable farm in the industry realizes a profit which is less than **entry**, and the least profitable firm's profit is greater than **bestopp**, the number of farms does not change.[19] Higher profits (above **entry**) stimulate entry and lower profits (below **bestopp**) trigger exit. **Bestopp** was assigned the value 600, about 5 percent less than the original profit level. **Entry** was assigned the value 900, half again as large as the exit threshold.

The entry threshold would be based on a return to the acquisition costs of the capital needed to enter the industry and the operator's income opportunity in the rest of the economy. The exit threshold would be based on the return to the salvage value of the capital invested in the farm and the operator's best oppor-

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[18] When the total number of farms in the industry changes, from entrants or exits, the slope of the market response functions does change even though the slope of the individual firm-level functions does not change.

[19] These opportunity thresholds are not observable (see footnote 10). The values assigned to them were consistent with the individual farm profits calculated in the model.

The longrun equilibrium profit per farm will be just greater than the exit threshold in the presence of "overshooting" (see Okun, Frankel, and Dornbush). The largest of the exit thresholds and the smallest of the entry thresholds are mathematical limits for the sequence of observations on per-firm profits. Control theorists define "overshoot" as the difference between the peak response and the steady-state response to a stimulus (Dorf, p. 102).

tunity wage outside the industry.[20] A second (lower) exit threshold would be based on the salvage return plus the next-best opportunity, which might represent retirement. This lower threshold is designated **nextopp**. Consequently, one exit occurs when profits are between **bestopp** and **nextopp**, and two exits occur when profits are below **nextopp**.[21] **Nextopp** was assigned the value 450, one-third less than **bestopp**, a difference somewhat less than the wage for hired labor.

The distribution of farms changes as farms switch from old technology to new technology and as entrants or exits occur. Entering farms employ the most profitable technology (that is, the new technology). Exiting farms leave the least profitable cohort.[22] Farms switch cohorts when the profit under the new technology exceeds the profit under the old technology by more than the amortized cost of the changeover (which has so far been assumed zero). The changeover accelerates when the profit under the old technology falls below a threshold, designated **ACCEL**, currently set at 300 (half the level of the highest exit opportunity). Thus, between successive solutions there is one changeover when the new-tech profit exceeds the old-tech profit and two changeovers when the new-tech profit exceeds the old-tech and the old-tech profit is less than **ACCEL**.

Successive solutions of the model constitute ordinal units of time. Translating those "ordinal" time units into "cardinal" years would entail, at minimum, recalibrating the entry, exit, and diffusion numbers from (0, 1, 2) to more "realistic" values. Perhaps, alternative mathematical rules would have to be

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[20] Sjaastad's 1962 article is the classic economic study of migration (one consequence of the exit decision). Price and Sikes' bibliography is an excellent entry into related literature. Guither and Hill interviewed Midwestern farmers who had chosen to leave farming. Diehl and Winkelman used census data to study the farm-nonfarm migration problem in the Southeast and in Minnesota, respectively. Kislev and Peterson (1981) examined the question of whether labor was pushed out by technology or drawn out by favorable opportunities. Barlett, Gladwin and Zabawa, and Ehrensaft and others are recent studies of firm-level adjustments to farm financial stress in Georgia, Florida, and Canada, respectively.

[21] Structural change would occur more rapidly if profits in each cohort are compared with the exit thresholds, rather than merely the highest profits. Under that formulation, as many as four exits would occur if each profit level fell below the level of **nextopp**. It might be desirable to integrate the adoption rules with the farm exit rules.

[22] The set of farms employing a particular technology constitutes a technological cohort. There are as many technological cohorts as there are distinct production functions in the industry.

Cohort 1 consists of firms using the original technology and cohort 2 consists of firms using the new technology. Literary reference to smaller, old-tech, less-profitable, traditional farms implies cohort 1. Text indicating larger, new-tech, more-profitable, commercial farms refers to cohort 2.

specified to govern the processes.[23] Bear in mind that each firm in the simulation model represents about 1 percent of the industry's production, a much larger share of output than any "typical" U.S. farm.

The input supply industry

Agriculture is assumed to obtain each of its inputs in markets where additional units can be had only at higher prices per unit. The supply function faced by agriculture for each of its inputs must be construed as net of the demands by the rest of the economy. The net input supply functions and the product demand function constitute the primary interaction of the rest of the economy with the industry. The entry and exit thresholds are a second point of influence of the rest of the economy on the industry under study.

In qualitative terms, labor supply is most price elastic and land supply is least price elastic. The supply elasticity for fertilizer lies in between. The form of the supply functions for each of these inputs is the same form as the supply in the industry being studied, except that the prices of the items used to produce these inputs are suppressed (assumed constant over all ranges of observation relevant to this analysis).[24]

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[23] The current specification of the diffusion accelerator in the TK!SOLVER (c) simulation model is STEP(ACCEL, LPROFO), which takes the value 1 when ACCEL is greater than or equal to LPROFO and is 0 elsewhere.

A more rapid rate of adoption would result from the specification INT((LPROFN-LPROFO)/MULT), which would take the value of the integer part of the ratio of the profit difference to the multiplier. LPROFN and LPROFO are lagged values of profits per firm under the new and old technology, respectively, and ACCEL and MULT are parameters of the relationships. This adoption rule is examined in the appendix. Larger values of ACCEL and smaller values of MULT accelerate the diffusion process.

A profit-dependent adoption rate which is initially small, but rises to a peak before declining could be simulated by replacing 1/MULT by a function depending on the time since introduction. One such function, defined for positive values of a and b and for nonnegative values of t, is given by:

$$G(t) = t^{a} e^{-bt}$$

which attains its maximum when t = a/b, and which is proportional to the Gamma (Erlangian) density function. The Gamma density is $G(t) * b^{a+1}/a!$, when a is an integer. If a is not an integer, a! is replaced by the Gamma(a+1) function; that is, the integral of the density over the range of t (see Feller, p. 46-7). The difference between the mean and the mode of a Gamma distribution is 1/b.

Year-to-year changes in the proportion of acreage planted to corn hybrids follow the pattern of a Gamma density [with a mean of 12.5 and mode of 10 years] more closely than a symmetric logistic density, as estimated by Griliches.

[24] Each input supply function has the algebraic form:

$$X(w) = cap + br2/w^{2},$$

where cap is the supply asymptote and br2 is the negative number which

The price elasticity along these functions varies from point to point. But the price elasticity, together with the original equilibrium point, was used to determine the parameters of the functions. The initial price elasticity assumed for the fertilizer industry was 2.0, which is consistent with 50-percent capacity utilization at that time. In the final equilibrium states, the capacity utilization exceeds 80 percent and the fertilizer elasticity drops below 0.5.

The land supply function assumed that the maximum potentially arable land was not more than 120 percent of the initial harvested acreage.[25] That assumption implied a price elasticity of 0.4 at the original equilibrium. As much as 95 percent of the potentially arable land is used during the simulation process, dropping the price elasticity of land supply to about 0.08. Large price increases are necessary to induce small increases in the quantity of land that is actually used in production (harvested or enrolled in the acreage diversion programs).

Labor, on the other hand, is assumed to be quite price responsive. Small increases in the wage rate induce large changes in the quantity employed, and large variations in the demand for labor are needed to substantially alter the going wage rate. At the starting point for the simulation, the price elasticity of labor supply was assumed to be 22, based on a labor supply asymptote which is 12 times the initial hired farm employment.[26]

The alternatives of a fixed wage for labor and a fixed quantity of land were considered in earlier analyses, as well as a fertilizer supply having an initial elasticity of 0.4.[27] Those simulations provided qualitative results similar to those presented here.

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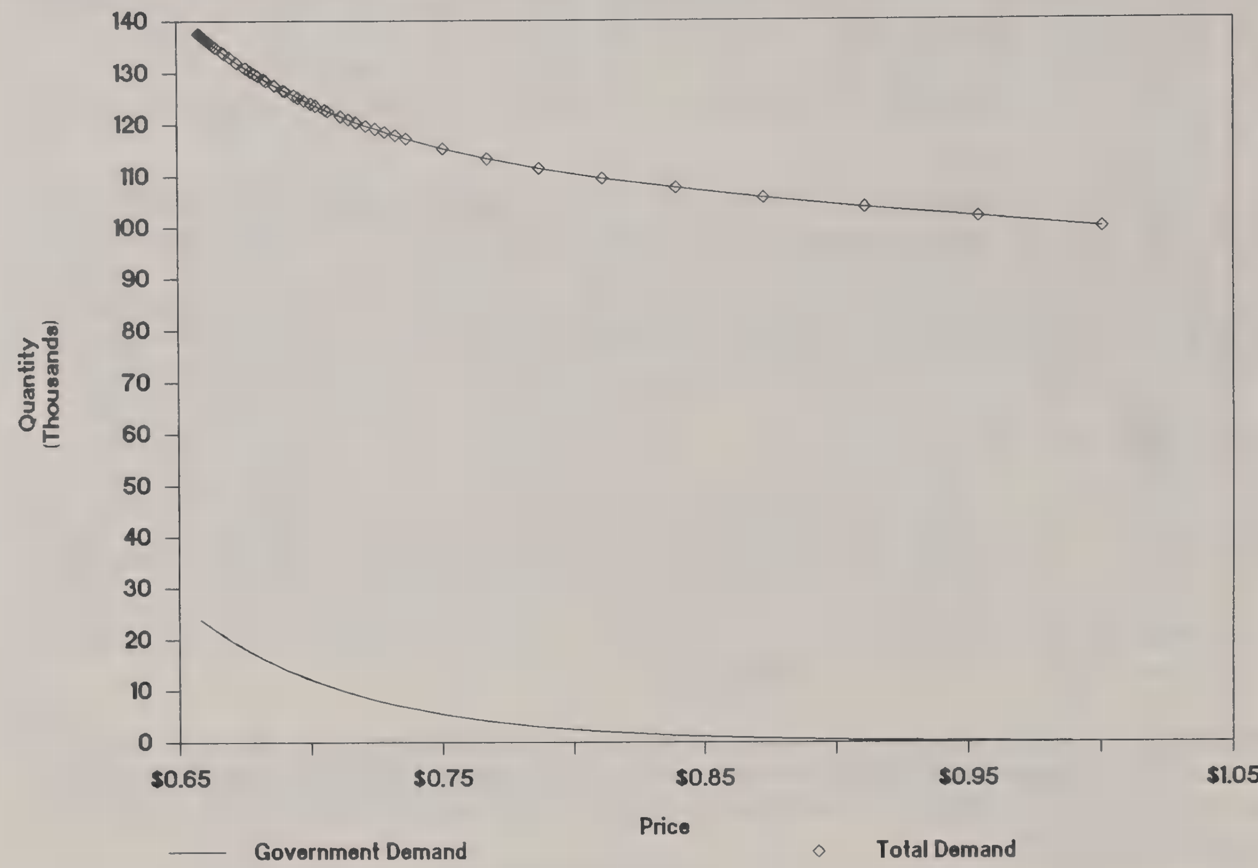
summarizes the effect of the inputs in its production and the inverse of the Hessian of its production function. The number of suppliers of the input X is implicit in the values assigned cap and br2. X is the quantity, and w is the price of the input in question.

[25] In the 1960s, the cropland harvest for all crops amounted to about 290 million acres. In the late 1970s and early 1980s, about 350 million acres were harvested. Cochrane and Ryan (p. 298) indicate that about 60 million acres were idled under programs in the 1960s. The record level of harvested cropland was 361 million acres in 1932, of which about 10 million acres were double-cropped. In 1977, the SCS Potential Cropland study estimated that at that time about 400 million acres were potentially arable. The price elasticity of land supply would be 0.22, if the capacity were 400 and the use were 360, given the assumed quadratic form of the response.

[26] This situation is similar to that which prevailed in the 1930s, when many of the farm programs were first enacted. At that time, the number of farm operators plus hired workers was equal to one-third of total U.S. employment. Total employment was assumed to be half of the potential number of workers.

[27] When both the fixed wage and the fixed land quantity were used, the resulting relative prices formed an observation matrix having rank 2 less than the rank needed to estimate (and hence, recover) the product supply function from the simulation model's solutions.

Figure 3: Government demand and total demand in response to product price



The product demand

The nongovernment demand for the output of the industry, including both exports and domestic use, is a linear function of the product price. At higher product prices, less of the product will be consumed (fig. 3). The effects of competing product prices, consumer disposable income, or number of consumers are embodied in the assumed parameters of the demand function. Moreover, the parameters are held constant over the period of the simulated technological diffusion. At the original equilibrium, the private demand function is inelastic, with elasticity assumed to be -0.4 at that point.[28] As the quantity marketed increases with the

[28] A considerable debate has focused on the elasticity of the demand for U.S. agricultural exports (Tweeten, Schuh, Chambers and Just (1979, 1981), Conway, Shei and Thompson, Johnson and others, Gardiner and Dixit, Davison and Arnade). With exports between 20 and 50 percent of the total demand, and substantial inelasticity of domestic use, the export elasticity would have to

spread of the new technology, the elasticity of demand diminishes.

Algebraically, the private demand function is of the explicit form:
quantity demanded = intercept + slope * price of output.
The slope and intercept implicitly reflect factors assumed constant for this analysis, which the reader might choose to vary.[29] The slope is a negative number and the intercept is a positive number.

A larger number of consumers would proportionally affect both the slope and intercept of the demand function. Changes in the prices of products which compete with the industry's output would affect the intercept of this demand function without altering the slope. Changing levels of the consumer's disposable income would disproportionately change both the slope and intercept of the private demand function.

Government intervention

Governmental action can change the outcome of the market in a number of ways. It can purchase the commodity in the product market. It can regulate the use of inputs (principally land) used in the production of the commodity. It can restrict the quantity of the commodity that participating producers can sell. It can directly make payments to individuals or farms involved in the production of the commodity. Each of these actions will be examined in this paper. Governmental interventions tied to the tax code or the credit system are not addressed here.

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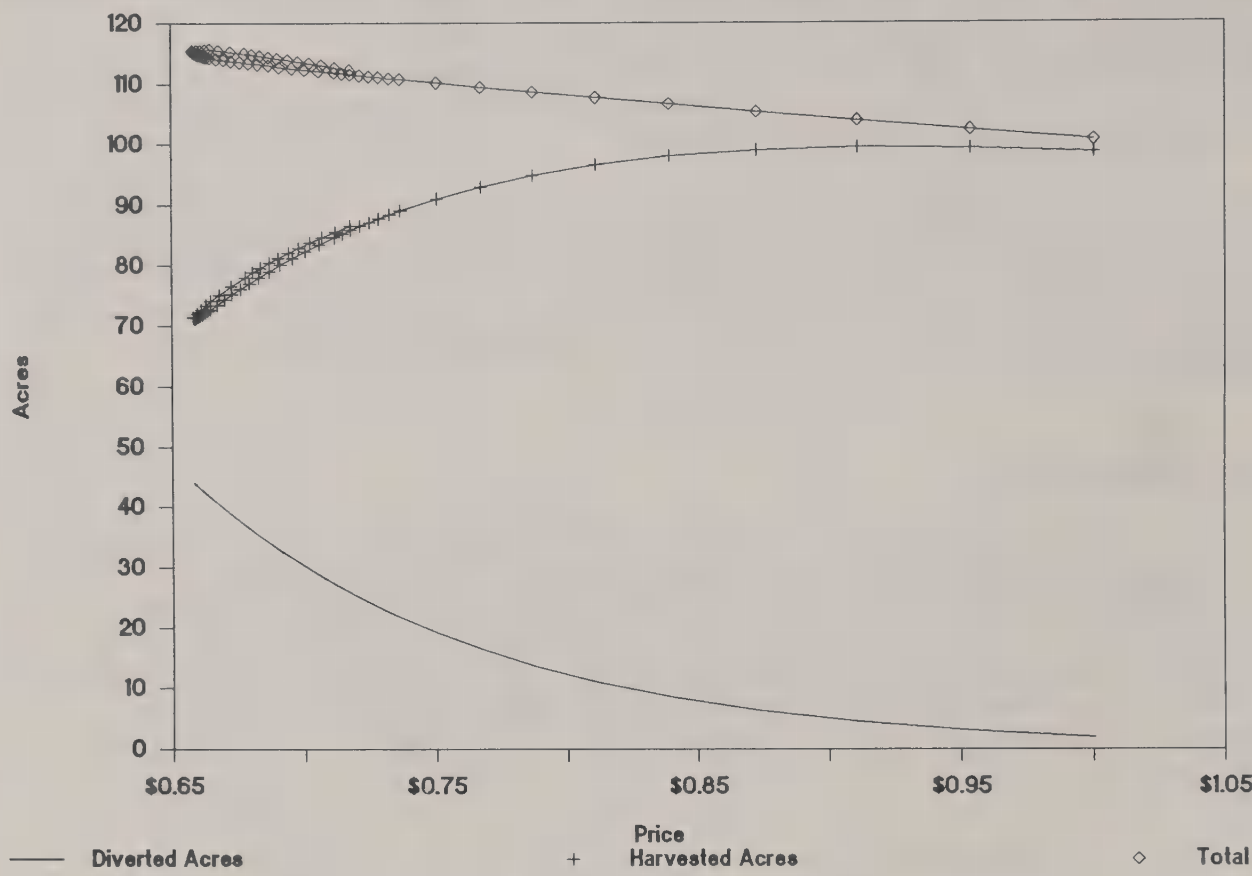
be 2 or larger to make the elasticity of total demand substantially greater than one.

Sensitivity analysis has shown that increasing the elasticity of private demand (for example to -1.1) has the same effect on the adjustment to the new technology as the operation of the government price support programs, except that the government expenditure is less (see appendix). Namely, more time elapses before a new equilibrium is reached, more output is produced, prices do not fall as rapidly or as much, and more farms enter the sector and more remain at the end.

[29] The mathematical expression of the discussion is the following:
QD = no. consumers * (a + (b * output price + c * other price)/consumer's wage)
where a, b, and c are invariant parameters, and the other factors could vary. In this experiment, only QD and output price are permitted to vary. Such a form would be obtained by aggregating functions derived at the individual or household level to the commodity market level.

To "internationalize" the model, one must add a function specifying the foreign production response to the endogenous (domestic) price and a function specifying foreign consumption response to the endogenous price to the model. Proper specification of those functions would entail currency exchange rates used in the manner outlined by Edwards (1987). The form of the consumption response would be linear in p and the production response would be linear in p^{-2}, both with negative coefficients.

Figure 4:   Government and private acreage response to product price



Harvested acreage and total arable land reflect the equilibrating input price response to product prices. Acreage diversion responds solely to product price.

Product market interventions will be called price supports (fig. 3). Input market interventions will be called acreage diversions (fig. 4). Direct payments to existing producers will be called parity income payments. Payments which are made to producers who are leaving or have left the industry will be called exit annuities, or "golden handshake" payments. Limitations on product sales will be called marketing quotas. In this discussion, these terms have a technical meaning that is particular to this simulation model (see box). The legislated instruments of the farm program having these names differ somewhat from the instruments in this model. They generally represent a mixture of these pure types of interventions with one thing (for example, acreage diversion) as a precondition for another (for example, price support).

Associated with each of these government interventions is a governmental expense incurred as a result of that program. In addition to these visible taxpayer costs are costs exacted from consumers in the form of higher prices and costs

Program — Definition within the simulator

Exit Annuity (Golden Handshake) -- Annual payment for life equal to AUHS to anyone leaving agriculture after its passage. The parameter AUHS has been set at about 8 percent of the original profit per farm, that is $50 units (15.8 percent, or $100 units, in a second simulation).

Parity Income -- Annual payment to all farmers equal to the difference between the parameter LVSTD and the average profit per farm (in the previous period). LVSTD has been set at a level ($550 units) which is about 87 percent of the original profit per farm. LVSTD should not exceed the entry threshold of profit per farm which (in the model) is 143 percent of the original profit level.

Price Support -- Government commodity purchase based on the difference between market price and the support levels. Demand by government is exponential (asymmetric around the support price) with a "large" elasticity, say around -16 initially. The price elasticity of expenditures under a price support program is one plus the price elasticity of the government demand function, initially -15 here. Support level (ps) is 90 percent of the initial price (p). Government commodity purchases were less than 1/2 of 1 percent of commodity production when price is at support level, rising to just under 20 percent at the peak level of purchases. GD = A * exp(B*(p - ps))

Acreage Diversion -- Government rental of land at the prevailing cash rents, based solely on the difference between output price (p) and support level (ps). Acreage demand by government is exponential with a "large" elasticity, say around -9 initially. The price elasticity of expenditure on acreage diversion is the sum of the price elasticity of acreage demand (-9) and the elasticity of cash rents with respect to the product price (which reflects interactions within the model and may be either positive or negative). About 5 percent of acreage would be diverted when the price is at the support level. As much as 80 percent of the arable land would be diverted under a pure acreage diversion program employing this demand function. GAD = AA * exp(BA*(p - ps))

Marketing Quota -- Annual restriction on sales by participating producers. Participating producers receive the higher of the support price (ps) or the market price (p) on the amount of the quota. When the market price is less than the support level, a government payment is made to all participants, in the amount of the difference times the quota. Program participation and quota levels are hereditary and continue, regardless of the technology employed by the farmer. New entrants to the industry are not subject to the quotas, but do not receive program payments, and receive only the market price for their output. The quota is set at 1,000 units, the original level of production per farm. The support level (ps) is 90 percent of the original market price.

imposed on farms due to the protracted adjustment process and the misleading incentives to enter the industry or delay leaving the industry. Some farms are induced falsely to switch from old to new technology, when the more appropriate choice would have been to leave the industry.

The simulation model calculates the direct government expenditure on the various interventions. Consumer costs are tracked via product prices and quantities, and the consumer surplus under the nongovernmental demand function. Adjustment costs can be inferred from the events giving rise to them: time to equilibrium, number of entrants and exits, number of exiting new-tech farms, and so on.

ADJUSTING TO NEW TECHNOLOGY

The adjustment to the new technology follows a characteristic pattern (fig. 5). In the product market, supply increases and the price falls. The new technology may or may not be profitable enough to induce new farms into the industry. If new farms enter the industry, the price decline is more precipitous. The new technology increases the demand for some inputs and reduces the demand for others, before the product price effects are felt. Consequently, some input prices rise and some may fall as a result of the technological change.

The lower product price and cost/price squeeze reduce the profits of all farms in the industry and force all farms to reduce output to more profitable levels. Figure 6 shows the response of farm-level profit to the product price. The larger farms' profit is more price-responsive than the smaller farms'.[30] Farms in every technological cohort make these output-reducing adjustments to lower prices and lower profits. Operators of farms which switch from the old-tech to the new-tech cohort are able to realize higher profits and produce a larger output than they would have, had they remained under their original technology. Only those switching modes of production improve their lot as the new technology spreads. Once they have switched, their profits and production begin to fall along with that of others in the new-tech cohort in response to the price effects of the technological treadmill (see fig. 5).

The profits ultimately fall below the threshold of opportunity for the marginal farms, and some farms leave the industry (see fig. 7). The exit choice may be voluntary, or it may be forced (as in bankruptcy).[31] As farms leave, the more extensive use of the resources causes the growth of output to slow and ultimately to reverse. Product prices begin to recover, input prices abate, and profit

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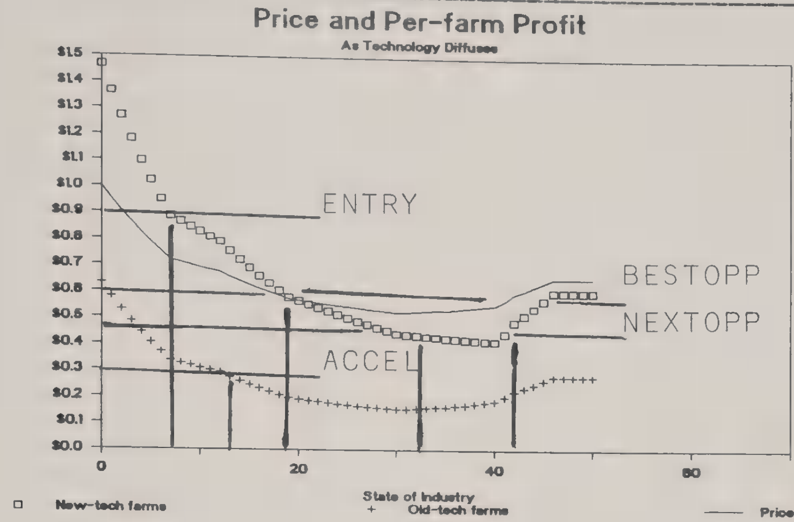
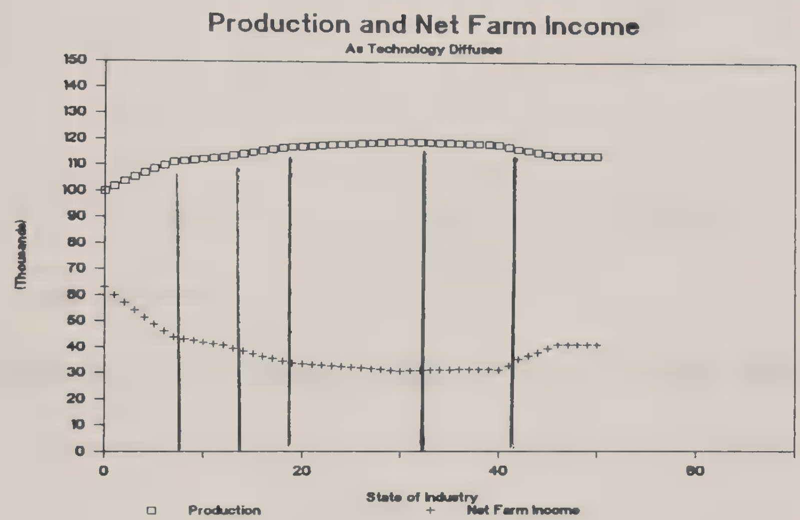
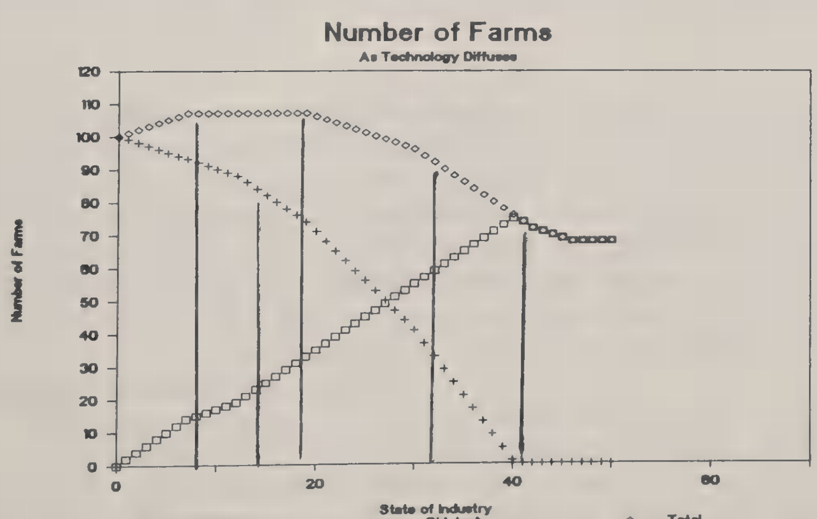
[30] Teigen (1987) found that the family income on farms with sales greater than $40,000 increased at three to five times the rate of price increase, while the incomes on the smallest farms (less than $10,000 sales) increased at rates smaller than the increase in product prices.

[31] Distinguishing between bankruptcy and voluntary exits would require an explicit submodel for the credit market. Lacking that submodel, "bankruptcy" and "exit" will be used synonymously.

Figure 5: Time pattern of adoption

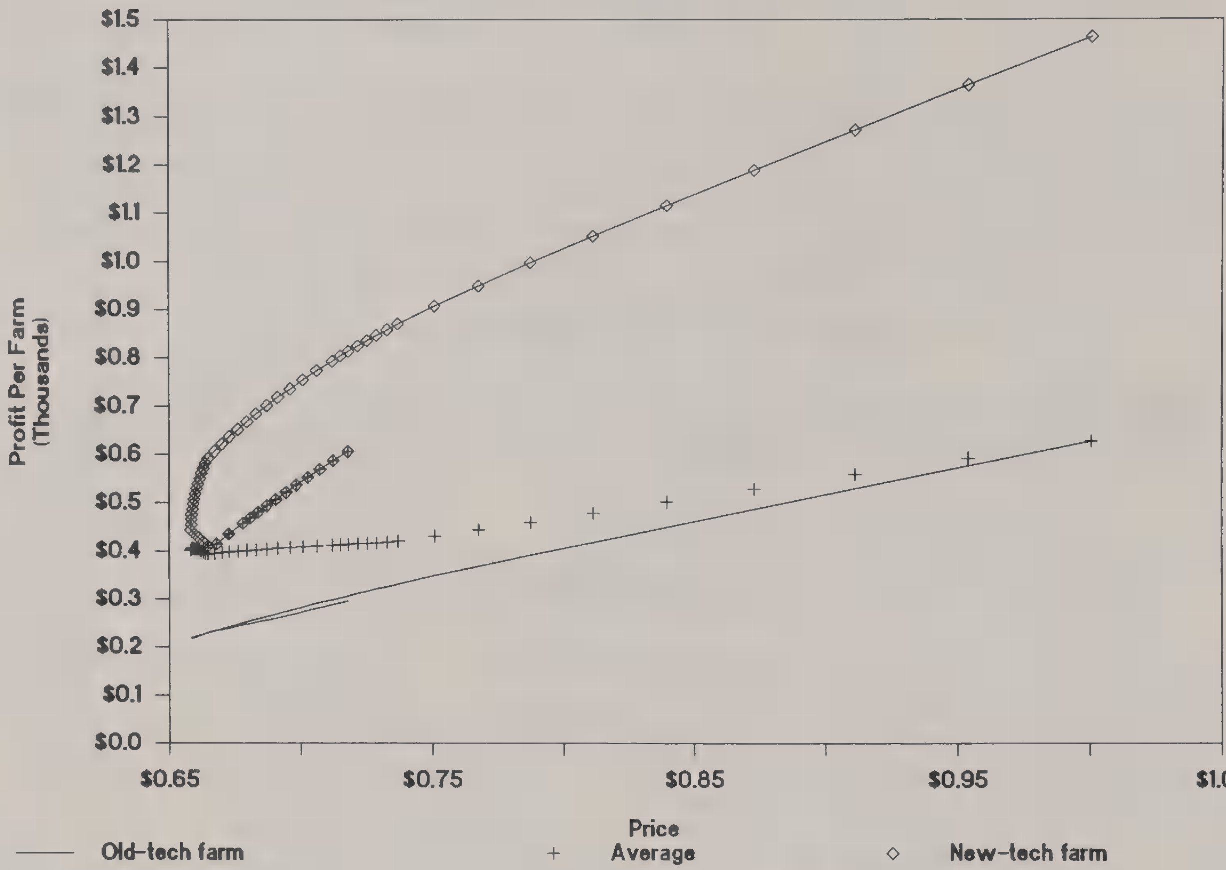






Each variable reflects its market equilibrium value in that state.

Figure 6: Profit per farm versus product price



Profit levels reflect equilibrium input price and quantity adjustments to product prices.

levels begin to recover.[32] As more farms leave the industry, the profits ultimately rise until even marginal farms earn more than their opportunities

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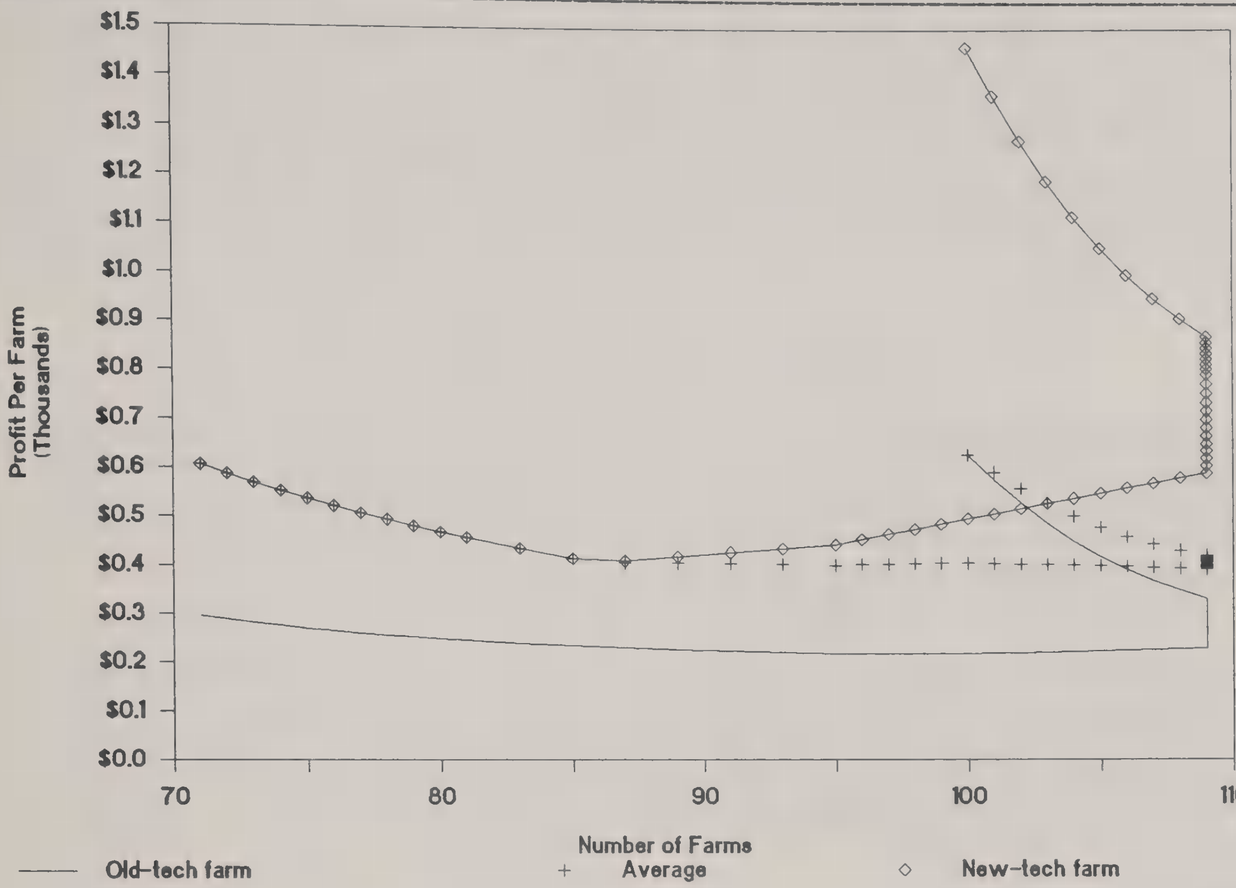
[32] A point is reached in the simulation model where the change in the number of farms fails to offset the product price effect, and the rental rate for land actually falls despite rising product prices. The degree to which this occurs depends on the extent that fertilizer, labor, and other input prices influence the demand for land. The output price elasticity of the demand for land is the negative of the sum of elasticities of land demand with respect to all input prices. The more that other inputs can substitute for land, the less is the product price elasticity (even to the point of becoming negative). In the scenarios examined here, the product price elasticity of acreage demand is assumed to be negative. The greater the extent that inputs complement land (as in fixed proportions), the greater is the product price elasticity. In the appendix, scenarios based on an elasticity of -0.1, rather than -0.78, show that the product price effect overtakes the technological shifts, reducing not only rental rates, but harvested acreage and total payments to landlords.

Figure 7: Profit per farm versus number of farms



Profit levels reflect equilibrium price and quantity adjustments to the number of farms.

outside the industry. At that point the adjustment is complete, and no further change occurs until the next technology is introduced or something changes in the product or input markets.

The longrun adjustment to new technology is greater output, lower product prices, fewer farms, and different returns to the owners of the productive resources in the industry. Some individuals are made better off (consumers and landowners), some are worse off (displaced farmers, farmworkers, and taxpayers when government programs are in place), and some emerge about the same (the remaining farmers). Technological change is not Pareto optimal.[33]

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[33] Seckler and Schmitz recognized this fact and tried to estimate the compensation necessary to maintain the welfare of the displaced workers (see their last sentence, in particular). Their partition of the benefits of the tomato harvester did not examine inputs other than labor.

The Luddites, who smashed early 19th-century industrial machinery in hopes of saving their jobs, viewed technology as an unmitigated evil. Technology could also be viewed as a mitigated good, which increases productivity and frees resources for other use. The impossibility of regulating the spread of technology in an open world economy was recognized even by the Luddites' prosecutor: "Were the use of machinery entirely to be abolished, the cessation of manufacture itself would soon follow, inasmuch as other countries, to which the machines would be banished, would be enabled to undersell us."[34] Replace the term "machinery" with the term "bovine somatotropin," and the problem is modernized.

GOVERNMENT PROGRAM EFFECTS

Government program instruments alter the industry's pattern of adjustment to the new technology. The baseline against which each of the government programs will be compared is the adjustment in a market unaffected by any government program. While such a comparison is possible in a simulated environment, precisely calibrating the response to match that of an industry with more than a half-century's experience with many forms of intervention is a difficult task.

The program instruments chosen for analysis are price supports, acreage diversion, marketing quotas, and direct income payments. Income payments to active farmers will be called parity income payments, while payments to exiting and former farmers will be called exit annuities. The primary beneficiaries of the acreage diversion program are the landowners, while the other programs benefit farm operators (a distinction easier to make within a model than in real life).

At the initial point of departure, before the introduction of the new technology, the industry equilibria were similar under each of the program alternatives. The same number of farms, nearly the same levels of production, price, and profit, and relatively low level of government expenditure describe each scenario (table 1).[35] As the technology begins to spread, the differences between the programs begin to appear.

Every program designed to aid farm operators (except the exit annuity and the acreage diversion) encouraged more farms to enter the industry than under the free market. These programs retard the rate at which farms leave the industry, and retard the rate at which they change from old to new technology. The adjustment process is drawn out in the presence of farm programs. More time elapses between the initial and final equilibrium. The government programs result in more farms adopting the new technology than the market can support,

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[34] "Proceedings held at the Castle of York, January 1813" in Introduction to Contemporary Civilization in the West, 3rd ed. (New York, Columbia University Press, 1961, II, 254-261. Reprinted in The New Technology and Human Values, ed. by John G. Burke, Wadsworth Publishing Co., 1966, p. 5.

[35] An appendix table presents the comparable results in the presence of the profit-proportional adoption rule. That adoption rate accelerates the diffusion of the technology and eliminates some of the transitory states early in the process, without affecting the final equilibrium of the system.

Table 1: Effect of government programs on simulated technological adoption

Variable		No government programs	Price supports and acreage diversion	Acreage diversion only	Price supports only	Price supports, acreage diversion, and parity income payments	Parity income payments only	Exit annuity $100 per year only	Exit annuity $50 per year only
					Number				
Steps to equilibrium	Technological	41	47	38	52	62	51	38	39
	Structural	46	59	43	67	87	64	43	45
Number of firms	Initial	100	100	100	100	100	100	100	100
	Maximum	107	109	107	109	111	109	107	107
	Final	68	71	65	74	71	68	65	66
New technology firms	Maximum	75	85	72	90	91	84	71	73
	Exits	7	14	7	16	20	16	6	7
					Dollars				
Net farm income	Initial	63,000	62,917	62,736	63,174	62,917	63,000	63,000	63,000
	Minimum	30,654	35,337	27,783	39,039	40,749	34,345	34,304	32,556
	Final	40,895	43,093	41,085	45,313	43,093	40,895	46,015	44,230
Landlord payments	Initial	7,000	7,161	7,172	6,992	7,161	7,000	7,000	7,000
	Maximum	11,462	17,366	17,608	14,371	18,551	12,714	10,857	11,135
	Final	9,257	12,623	11,537	10,653	12,623	9,257	8,241	8,594
Output price	Initial	1.000	1.001	0.999	1.002	1.001	1.000	1.000	1.000
	Minimum	.524	.659	.574	.649	.649	.467	.568	.547
	Final	.655	.718	.700	.702	.718	.655	.710	.691
					Units				
Output produced	Initial	100,000	100,075	100,046	100,029	100,075	100,000	100,000	100,000
	Maximum	119,045	137,609	117,030	141,985	141,702	121,340	117,275	118,133
	Final	113,818	120,529	111,998	123,707	120,529	113,818	111,589	112,374
					Dollars				
Government cost	Initial	0	244	146	98	244	0	0	0
	Maximum	0	23,937	14,188	18,114	34,750	16,277	4,200	2,050
	Final	0	9,530	3,144	8,291	9,530	0	4,200	2,050
Parity income payment	Maximum/farm	0	0	0	0	94.0	150.9	0	0
					Units				
Government commodity purchases	Maximum	0	23,745	0	27,928	27,669	0	0	0
	Final	0	9,238	0	11,804	9,238	0	0	0
					Acres				
Government acreage diversion	Maximum	0	43.9	93.8	0	47.8	0	0	0
	Final	0	25.8	30.2	0	25.8	0	0	0
Acreage harvested	Initial	100.0	98.6	98.6	100.0	98.6	100.0	100.0	100.0
	Extremum	110.8	71.3	21.9	113.9	67.8	112.4	109.9	110.4
	Final	106.9	86.5	80.7	109.6	86.5	106.9	104.3	105.3
					Units				
Output per acre (sector)	Maximum	1,074.1	1,928.9	5,335.0	1,253.4	2,088.2	1,082.0	1,069.8	1,070.3
	Final	1,064.5	1,394.0	1,387.8	1,128.5	1,394.0	1,064.5	1,069.8	1,067.3
Output per acre (innovators)	Maximum	2,045.9	2,748.4	8,335.5	2,046.9	2,896.5	2,045.9	2,045.9	2,199.5
	Final	1,064.5	1,394.0	1,387.8	1,128.5	1,394.0	1,064.5	1,069.8	1,067.3
					Response				
Supply elasticity	Initial	0.217	0.216	0.216	0.217	0.216	0.217	0.217	0.217
	Maximum	.666	.626	.617	.646	.706	.887	.563	.609
	Final	.460	.425	.390	.463	.425	.460	.398	.418

and a greater number of new technology farms are forced to exit than under the free market. More farms survive to the final equilibrium state in the presence of such programs than under the free market, but the per-farm profits are not substantially higher under those programs. This modest increase in the number of surviving farms is the only extent to which farm program instruments have actually "saved the family farm."

The pure acreage diversion program and the exit annuity program have different effects. By competing with the farm operators in the land market, the government increases input costs under the acreage diversion program and squeezes their profit margin.[36] The tighter profit margin attracts fewer farms into the industry and encourages operators to hasten their substitution of new technology for the expensive land resource. Both net farm income and landlord payments end up higher than under the free market simulation, with their sum reflecting $0.78 on the dollar of government expenditure.

In the simulation, fewer farms remained under the acreage diversion program than under the free market case. Although the per-farm profit under the acreage diversion program exceeded that of the free market, that difference reflects a numerical coincidence,[37] because the exit threshold, which governs the final profit level, is the same in both cases.

The exit annuity increases the threshold of off-farm opportunity to levels above the exit threshold of the free market and other programs. Consequently, the profit realized by farmers remaining in equilibrium is substantially higher than under the free market. The higher exit threshold is reached earlier in the adjustment process, accelerating the process. Given the more rapid adjustment, fewer farms are attracted into the new technology, only to later exit, and a smaller number of farms remain in the final state. In the final state, net farm income is higher and landlord payments (probably parameter-dependent) are lower than under the free market scenario.

The sum of the net farm income and the landlord payments exceeds the sum in the free market case by an amount nearly equal to the amount of the annuity payments, even though the recipients of those payments are now outside the industry. In essence, today's farmers (those who continue plus those who exit)

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[36] At its peak level, more than three-quarters of the arable land is diverted from production, but factor substitution and the more intensive use of the remaining land raised yields to more than four times the original level. Consequently, the reduction in output relative to the free market is less than 2 percent.

The numerical magnitude of this yield effect is probably greater than evident (in cardinal terms) under current programs. Yet, the example serves as an ordinal caution, regarding the potential response to farm program incentives absent any variation in technology. Ericksen termed this phenomenon the "slippage effect."

[37] The profit under the next to the last solution was closer to the exit threshold than in other scenarios. With the discreteness of the supply and price response, a large overshoot of the threshold occurred.

would receive $2.00 in benefit from every dollar spent on a annuity program whose payments are made solely to farmers choosing to leave the industry. Moreover, the maximum cost of such a program to the taxpayer is between one-third and one-eighth the cost of the other modes of government intervention.[38]

The combination of price supports and acreage diversion is most like the current commodity program. The cost of the combined program is higher than the cost of either program by itself (nearly equal to the cost of one plus half the cost of the other). The sum of net farm income and landlord payments is higher than that in the free market case by an amount equal to $0.58 for every dollar spent on those government programs.[39] The final equilibrium has more farms (and is achieved more slowly) than under the free market, but has fewer farms and more rapid adjustment than the pure price support program. The number of new-tech farms that do not survive is about twice the number under the free market, but not as many as under the pure price support program. The peak level of acreage diversion is about half the level under the pure acreage diversion program. Yields rise, and despite the acreage reduction, total output exceeds that in the free market case.

The parity income program entailed payments to producers equal to the difference between a pre-set living standard and the last year's average farm income. The living standard was assumed to be less than the exit threshold, and so did not affect the final number of farms in the industry.[40] However, the payments have the potential to attract new farms into the industry. The government expenditure under this parity income program was comparable to that under either the pure price support or pure acreage diversion program. The parity income program affects the product and input markets only indirectly, via the number of farms which are sustained by those direct payments. The benefits to farmers and

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[38] If an exit annuity program was designed for U.S. agriculture, limiting eligibility to the largest (maybe one-third) of the farms would be cost-effective. The size and productivity of farms with sales less than $40,000 suggest that a significant number of exits in this category would have minimal effect on total farm output.

[39] It is $0.70 in the case of price supports alone and $0.78 in the case of acreage diversion alone. For the $100 exit annuity, it is $0.98 and it is $1.30 for the $50 annuity.

For comparison, O'Brien (p. xi) estimated that government expenditure of $3 was necessary to purchase enough commodities on the open market to raise net farm income about $1 under the terms of permanent legislation. He made no estimate of the landlords' receipts. Harrington and others have found that programs tend to benefit landowners more than farm operators.

[40] If the living standard exceeded the exit threshold, the result would be more farms in the final equilibrium and a longer time to equilibrium. Exits would occur in alternating years, instead of the continuous process, when the spread of new technology depresses profits despite the payments being momentarily below the exit threshold. The longrun equilibrium profit in this case would be the parity living standard, rather than the exit threshold.

landlords per dollar of expenditure on parity income payments is smallest of all the programs.[41]

Marketing quotas retard the adoption of new technology to the slowest rate among all the policy regimes examined (table 2). The payments to producers based on the support price increased the low-tech producers' incomes enough to keep them above the threshold accelerating adoption and kept the high-tech producers' incomes above the exit thresholds. Net farm income for the sector ultimately exceeded the initial income levels, reflecting both the magnitude of government payments and the number of farms. Long-term equilibrium profit of the new-tech firms in the program was about 7 percent higher than the initial profit level. Nonprogram firms' profit was about 7 percent higher than progam participants' profit. Landlord payments are comparable to levels accruing under the price support scenario. Under the pure marketing quota scenario, six firms entered the industry (outside the quota program) and no firms left the industry. The nonprogram firms produce about 10 percent of the total output. Equilibrium price levels under marketing quotas are higher than under the other program options. Government cost of the marketing quota program in the steady-state exceeds that of other programs, although the transient cost of several price support alternatives exceeded the marketing quota cost.

When the marketing quota is combined with a $100 exit annuity, an interesting adjustment process occurs. The early periods proceed in the same, slow deliberate manner as the pure marketing quota. But, when the profits reach the exit threshold augmented by the annuity, a process of exit and replacement begins. With a $100 annuity, the first exit occurs in the 77th solution state (year) of the model. The reduced production raises product prices, reducing government cost of the quota program, and raising the incomes of nonparticipating farmers. Participants in the quota program experience minimal changes in their incomes (responding only to input price changes), since the support level and the quota determine their revenue. By the 82nd solution state, the nonparticipants' income has risen above the entry threshold and entry resumes. Since the nonparticipants' production is nearly twice (1,875 vs. 1,000) that of the quota participants, more exits than entries must occur. For about 28 solutions, the price effects of the exits reduce the marketing quota expenditure more than the increase in annuity payments, and total government outlays decline. In the ultimate equilibrium (after 128 solutions), total government expenditure is about 53 percent of the maximum payment under the marketing quota alone. In the longrun equilibrium, nonparticipants' profits are just under the entry threshold and quota participants' profits are just above the exit threshold. The 50 firms remaining in the quota program produce 46.5 percent of the output, while the 31 nonparticipating firms produce 53.5 percent and realize nearly 44 percent of the net income of the industry.

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[41] The decoupled income payments under proposals like the Boschwitz plan (S. 1725, the Family Farm Protection Act) are computed differently from these "parity income payments," but are made to existing (continuing) farmers. Consequently, their effectiveness in terms of dollars of farm income per dollar of government expenditure should be similar to that under the "parity income payment" scenario.

Table 2: Effect of government programs on simulated technological adoption

Variable		No government programs	Marketing quota	Marketing quota and $100 exit annuity
		Number		
Steps to equilibrium	Technological	41	100	89
	Structural	46	100	128
Number of firms	Initial	100	100	100
	Maximum	107	106	106
	Final	68	106	81
New technology firms	Maximum	75	106	98
	Exits	7	0	17
		Dollars		
Net farm income	Initial	63,000	63,000	63,000
	Minimum	30,654	55,825	55,825
	Maximum		71,924	69,692
	Final	40,895	71,924	62,421
Landlord payments	Initial	7,000	7,000	7,000
	Maximum	11,462	14,226	13,710
	Final	9,257	14,226	12,159
Output price	Initial	1.000	1.000	1.000
	Minimum	.524	.722	.722
	Local max.			.837
	Final	.655	.726	.810
		Units		
Output produced	Initial	100,000	100,000	100,000
	Maximum	119,045	111,115	111,115
	Local min.			106,504
	Final	113,818	110,954	107,604
		Dollars		
Government cost	Initial	0	0	0
	Maximum	0	17,788	17,788
	Local min.			7,494
	Final	0	17,386	9,505
		Acres		
Acreage harvested	Initial	100.0	100.0	100.0
	Extremum	110.8	113.7	113.3
	Final	106.9	113.7	111.7
		Units		
Output per acre (sector)	Maximum	1,074.1	1,052.8	1,052.8
	Final	1,064.5	975.5	963.1
Output per acre (innovators)	Maximum	2,045.9	908.3	824.8
	Final	1,064.5	908.3	583.7
Output per acre (nonparticipants)	Extremum		1,640.5	3,161.2
	Final		3,011.7	2,209.5
		Response		
Supply elasticity	Initial	0.217	0.000	0.000
	Maximum	.666	.025	.120
	Final	.460	.025	.116

Table 3: Equilibrium characteristics of new-technology firms

Characteristic	Free market	Marketing quota program		Marketing quota and $100 annuity	
		Participant	Nonparticipant	Participant	Nonparticipant
			Dollars		
Marginal cost	0.655	0.341	0.726	0.352	0.810
			Units		
Production	1,637.8	1,000.0	1,827.7	1,000.0	1,858.2
Hired labor	-.202	-.678	.273	-.903	.236
Fertilizer	2.402	1.387	3.132	1.194	3.159
Land	1.572	1.101	.606	1.713	.841
			Dollars		
Profit	601.39	676.11	718.92	700.44	883.86
			Number		
Surviving firms	68	100	6	50	31
			Dollars		
Input prices:					
Labor	190.40		186.41		188.54
Fertilizer	165.70		153.34		153.58
Land	86.58		125.08		108.83

An examination of the resource allocation within the simulated firms of the model can shed light on the decision to participate in government programs.[42] Participants in the marketing quota program are compared with nonparticipants and producers under the free market scenario (table 3). With the new technology

[42] Floyd's paper is one of the early analyses of resource allocation in the presence and absence of government farm progams.

of production, the marginal cost for participating farms is $0.34 - $0.35 per unit of output compared with the market price (and marginal cost for nonparticipants) of $0.73 - $0.81. The marginal cost under the old technology is about $1.10 in the final equilibrium. In the free market, the marginal cost (= price) is $0.65. Given the model's parameters, participating producers used more land and less labor than nonparticipants. Nonparticipants used substantially more fertilizer than program participants and realized higher per-acre yields. The negative values for hired labor imply that the farm operator is working part-time off the farm, rather than hiring any workers. Program participants use their land extensively and work part-time off the farm, while nonparticipants hire labor and use their land intensively (according to this model's parameters). The free market equilibrium had some off-farm work, more acreage than under the pure quota program, and an intermediate level of fertilizer use. Nonparticipants' profits exceeded those of participants and the disparity between the marginal cost and price provides an incentive for participants to "cheat" and produce more than the quota.

Under all the programs that have been examined, except the exit annuity, the direct beneficiaries are existing farmers and landowners. The payments they receive induce them to remain in the industry despite market signals to the contrary. Because the programs do nothing to affect the threshold of opportunity outside the industry, the programs cannot affect the longrun profit of the farms. Consequently, they lock those farms in "golden handcuffs" which cost the taxpayers without enriching any farm.

Only the exit annuity alters the threshold of opportunity enough to affect the longrun profit of farms in the industry.[43] The market's response to the departing farms raised the profits of remaining farms, nearly dollar-for-dollar with the exit annuity in the simulation model. Considering the simulated benefit of nearly $2.00 in benefit to current and one-time farmers and landowners for every annuity dollar paid, marginal income tax collections from the simultated results could make this a not-quite self-financing income transfer program.

CONCLUSIONS

Technology exerts a continuing pressure on the supply side of the product market and the demand side of input markets. It relieves the pressure applied by population on the demand side and exhaustible resources in the input markets. The balance between these forces determines the long-term trends in commodity prices, industry output, and the number of farms.

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[43] Any change in the nonfarm opportunity has the same effect as the exit annuity. Employment growth in industries for which farmers' skills would easily transfer would increase the threshold just like the exit annuity payment. Construction of the interstate highway system employed equipment operators whose skills resembled those of tractor operators. The welfare programs in the North may have bid many of the one-time sharecroppers out of agriculture in the 1960s, or at least provided a "safety net" beneath the nonfarm opportunities which in fact bid them out.

For more than a half-century, the real prices of farm commodities have declined in the face of soaring production levels and the number of farms has fallen to less than a third of the record levels of the 1930s. Farmer interests have tried to design instruments of public policy that would counteract those trends and facilitate the adjustments in the economy. Farm policy has failed to reverse these trends. To the extent that farm policy has been successful, it has slowed the adjustments to the relentless pressure of technology to a rate the nonfarm economy could absorb.

The structure of the industry has evolved from many small homogeneous (even self-sufficient) farms, to a mixture of small and large commercial farms, to an industry of commercial farms containing only a vestige of the original small farms. Yet, the incomes of these larger farms have improved only to the extent that their operators' opportunities, and awareness of those opportunities, have improved in the rest of the economy.

Returning to the price levels of times long gone appeals to many farmers, as evident in their calls for "parity." But the taxpayer costs are substantial. Moreover, when the structural adjustments wash through the system, the larger pie is simply divided in more pieces, and each piece of the profit pie is no larger than before.

Why has U.S. agriculture not experienced the exit of larger farms predicted by the structural adjustments in the model? Large farms' incomes apparently exceed their opportunities outside of agriculture.[44] The exits of small to midsize farms has not affected total farm output enough to raise product prices, because their resources are being employed by firms using technologies which are at least as advanced as the exiting firms. With the higher technologies, those resources may be even more productive than they were in their former operation. Relative to the adoption curve in figure 5, the U.S. agricultural sector has not reached the right-most stage of the structural adjustments, where larger, high-technology firms begin to leave the industry.[45] Farm product prices consequently continue to fall despite decreasing farm numbers as technological change proceeds.

What about the absorption of displaced farmers in the nonfarm economy? Between the mid-1930s and mid-1970s, the number of farms declined from 6.8 million to about 2.5 million and farm employment dropped from about 10 million to about 3.5 million. Yet the number of unemployed workers indicates that the nonfarm economy has absorbed these workers with a minimum of friction. To the extent

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[44] Farms selling more than $100,000 in commodities have generated family incomes which have always exceeded that of the median U.S. family (Teigen, 1987). The farms' resource returns must have also exceeded the returns accruing to the salvage value of the capital invested in agriculture, in addition to return on the family's labor.

[45] In the financial crisis of the early 1980s, the U.S. farm sector may have approached a stage where larger, more progressive farms were at risk of bankruptcy.

that the farm exits were retirees, the economic adjustment was even easier. The social costs of the displaced workers arise when the only opportunities of the displaced worker are unemployment or the "welfare" program (Seckler and Schmitz). I have seen no data indicating the potential increase in the "welfare" participants which could be attributed to technological advance in agriculture. Most of the people who left agriculture adapted well to the nonfarm economy and did not permanently increase the number of "welfare" participants (Price and Sikes).

What would happen if government intervention in agriculture ceased? In the context of this model, the answer is that the number of farms would fall, the remaining farms would grow, new technologies would be adopted more rapidly, and product prices would fall. Traditional farm policy has raised commodity prices in an attempt to enhance the incomes of farmers. But the longrun income position of farmers is determined by the viable economic opportunities outside the farm sector, and these are not affected by farm policy in its current form. The farm programs do increase the number of farms, relative to a free-market scenario, and do increase product prices. But, the increased number of farmers bidding for the fixed resources in agriculture (primarily land) increases the value of land to the benefit of landowners and landlords at the expense of the farm operator. Past farm programs bought time for the nonfarm economy to absorb the farmers displaced by advancing technology and prevented a measurable increase in unemployment due to the structural changes in farming.

But, farm programs can also facilitate structural change. The exit annuity increased the incomes of both continuing farmers and those who chose to leave. The adoption of new technology would increase more rapidly in response to the market-oriented price and profit signals experienced by farms. Commodity prices would no longer be distorted and specific commodity producers would no longer gain in relation to nonprogram producers. Commodities would trade on the basis of the free market's demand and supply, and farm inputs would be valued based on those free-market prices. The taxpayer cost of an exit annuity program could be substantially less than current programs, since it depends on the number of farm-leavers rather than the number of continuing farm operators. Although there would be regional differences in effect, absorbing the potential farm-leavers in today's economy of 110 million jobs will be easier than absorbing the farm-leavers in the 55-million-job economy right after World War II.

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APPENDIX

Sensitivity Analysis

The validation of the model involved examining the sensitivity of its results to variations in the parameters in its relationships as well as varying the mathematical form of the relationships. The relationship governing the technology adoption decision was changed so that the number of adopters was proportional to the profit margin between the two technologies rather than the step-function response discussed in the main text. The initial elasticity of product demand was changed to -1.1, from the -0.4 used in the scenarios discussed above. A scenario using firm-level Cobb-Douglas production functions was examined to contrast with the quadratic functions used in the main text. A quadratic production function with parameters inspired by Binswanger's elasticities was used to analyze the major policy options studied in the text.

Adoption rate: When the profit margin favors the new technology over the old, we expect adoption to occur. The ordinal time units in the simulation model are defined by the occurrence of an event marking technological adoption or entry or exit. The adoption rule in the basic simulator was kept simple in order to facilitate understanding of the process. The number of adopters was equal to one if new-tech profit exceeded old-tech profit, and two if the new-tech profit exceeded the old-tech profit and the old-tech profit was less than **accel**, a threshold which was equal to one-half the highest exit threshold. In the TK!SOLVER (c) simulation model, this accelerator is given by STEP(ACCEL, LPROFO), which takes the value 1 when ACCEL is greater than or equal to LPROFO and is 0 elsewhere.

An alternative adoption rate was specified in which the number of adopters was proportional to the profit margin between old-tech and new-tech firms. In particular, the number of adopters increased by one for every $200 of additional profit under the new technology. In addition, a base level of one adopter remained as long as the new-tech profit exceeded the old-tech profit. In the TK!SOLVER model, this rule is given by INT((LPROFN-LPROFO)/MULT), whose value is the integer part of the ratio of the profit difference to the multiplier. LPROFN and LPROFO are lagged values of profits per firm under the new and old technology, respectively, and ACCEL and MULT are parameters. Larger values of ACCEL and smaller values of MULT accelerate the diffusion process.

This alternative rule increased the rate of adoption in the early periods of the simulation. This adoption rule reduced the time to the new equilibrium (app. table 1). The more-rapid equilibrium process changed the transient behavior of the system without affecting the final steady-state equilibrium values. The more rapid adoption of the new technology reduced the number of entrants. Consequently, the number of exits was also reduced. Prices and net farm income did not decline as much as with the other adoption rule, so that the maximum governmental expenditure was reduced under all options. Since the longrun cost of the programs is the same as with the original adoption rules, the ranking by cost-effectiveness of the policy instruments remains the same.

Under this adoption rule, technological adoption occurs most rapidly early after the introduction of the new technology, while under the rule used in the main

Appendix table 1: Effect of government programs on simulated technological adoption (profit-proportional adoption rate)

Variable		No government programs	Price supports and acreage diversion	Acreage diversion only	Price supports only	Price supports, acreage diversion, and parity income payments	Parity income payments only	Exit annuity $100 per year only	Exit annuity $50 per year only
					Number				
Steps to equilibrium	Technological	29	33	29	34	37	35	27	28
	Structural	35	44	34	48	54	45	32	34
Number of firms	Initial	100	100	100	100	100	100	100	100
	Maximum	104	105	103	105	105	104	104	104
	Final	68	71	65	74	71	68	65	66
New technology firms	Maximum	75	84	71	89	88	80	71	73
	Exits	7	13	6	15	17	12	[illegible]	7
					Dollars				
Net farm income	Initial	63,000	62,917	62,735	63,174	62,917	63,000	63,000	63,000
	Minimum	31,381	35,744	29,086	39,397	40,590	33,577	34,303	32,759
	Final	40,894	43,092	41,084	45,312	43,092	40,894	46,014	44,229
Landlord payments	Initial	7,000	7,161	7,172	6,992	7,161	7,000	7,000	7,000
	Maximum	11,359	17,080	17,355	14,217	17,977	12,331	10,851	11,102
	Final	9,257	12,623	11,537	10,653	12,623	9,257	8,242	8,594
Output price	Initial	1.000	1.001	0.999	1.002	1.001	1.000	1.000	1.000
	Minimum	.531	.663	.580	.653	.655	.481	.568	.548
	Final	.655	.718	.700	.702	.718	.655	.710	.691
					Units				
Output produced	Initial	100,000	100,075	100,046	100,029	100,075	100,000	100,000	100,000
	Maximum	118,774	135,831	116,793	140,002	138,786	120,745	117,275	118,074
	Final	113,818	120,529	111,998	123,708	120,529	113,818	111,589	112,374
					Dollars				
Government cost	Initial	0	244	146	98	244	0	0	0
	Maximum	0	20,996	13,320	17,046	31,391	15,055	3,900	1,900
	Final	0	9,530	3,145	8,291	9,238	0	3,900	1,900
Parity income payment	Maximum/farm	0	0	0	0	87.9	147.6	0	0
					Units				
Government commodity purchases	Maximum	0	22,333	0	26,113	25,005	0	0	0
	Final	0	9,238	0	11,804	9,238	0	0	0
					Acres				
Government acreage diversion	Maximum	0	42.4	88.9	0	45.2	0	0	0
	Final	0	25.8	30.2	0	25.8	0	0	0
Acreage harvested	Initial	100.0	98.6	98.6	100.0	98.6	100.0	100.0	100.0
	Extremum	110.7	72.8	26.7	113.7	70.3	111.9	109.9	110.3
	Final	106.9	86.5	80.7	109.6	86.5	106.9	104.3	105.3
					Units				
Output per acre (sector)	Maximum	1,073.0	1,863.5	4,373.4	1,238.3	1,973.5	1,079.2	1,069.8	1,070.3
	Final	1,064.5	1,394.0	1,387.8	1,128.5	1,394.0	1,064.5	1,069.8	1,067.3
Output per acre (innovators)	Maximum	2,045.9	2,582.6	6,334.2	2,046.5	2,624.5	2,045.9	2,045.9	2,045.9
	Final	1,064.5	1,394.0	1,387.8	1,128.5	1,394.0	1,064.5	1,069.8	1,067.3
					Response				
Supply elasticity	Initial	.217	.216	.216	.217	.216	.217	.217	.217
	Maximum	.648	.607	.595	.638	.666	.820	.563	.605
	Final	.460	.425	.390	.463	.425	.460	.398	.418

text, the highest adoption rates occur in the later stages of its availability. Many technologies have shown adoption rates which are slow at first, rise to a peak, and then decline. For example, the adoption of corn hybrids followed such a pattern of rise and decline.

In particular, the year-to-year changes in the acreage planted to hybrids followed a pattern similar to a Gamma density function with a mean of 12.5 and a mode of 10 years. Griliches approximated the cumulative adoption by a logistic function which has a symmetric density function.

An adoption rate which is initially small, but rises to a peak before declining, could be simulated using a function depending on the time since introduction. One such function, defined for positive values of a and b and for nonnegative values of t, is given by: $G(t) = t^a e^{-bt}$, which attains its maximum when $t = a/b$, and which is proportional to the Gamma (Erlangian) density function. The Gamma density is $G(t) * b^{a+1}/a!$, when a is an integer. If a is not an integer, a! is replaced by the Gamma(a+1) function; that is, the integral of the density (G) over the range of t (see Feller, p. 46-7). The difference between the mean and the mode of a Gamma distribution is 1/b.

In the TK!SOLVER (c) simulator, I would represent the corn hybrid adoption pattern by $INT(NT * G(t) * b^{a+1}/a!)$, where NT is the number of traditional farms, a and b are parameters of the Gamma function, and G(t) is the time-dependent portion of the Gamma density. INT( ) returns the integer part of the term in the parentheses.

A somewhat simpler function depicting a rise-and-decline pattern of adoption, which is related to the logistic curve,[46] is given by INT(c * (1 + NI)*(1 + NT)/(NF)) * STEP(LPROFN, LPROFO) , where NI is the number of innovators, NT is the number of traditional farms, NF is the total number of farms, and c is a scaling constant. Lprofn and lprofo are the lagged profit values for new-tech and old-tech firms. The functions INT( ) and STEP( ) have already been defined.

The rules governing the adoption rates are not readily observable and continuing experimentation would refine the simulation results. Further research would examine alternative rules governing the exit and entry events.

Demand elasticity: The main text analyzed scenarios based on an inelastic demand for the output of the industry. A larger elasticity might represent the response along one country's net export demand, given the production responses of other countries. The nongovernmental demand in the main text was specified as a linear function with an elasticity of -0.4 when the price is $1.00 and consumption is 100,000 units. The alternative demand function, examined in this appendix, was specified with an elasticity of -1.1 at a price of $1.00 and quantity 100,000 units.

---

[46] $X(t) = N / (1 + (N-1)e^{-kt})$ satisfies the differential equation: $(dX/dt) = k X (N-X) / N$, given initial conditions of $X = 1$ when $t = 0$ (Coleman, p. 43).

Appendix table 2: Effect of government programs on simulated technological adoption (initial demand elasticity = -1.1)

Variable		No government programs	Price supports and acreage diversion	Acreage diversion only	Price supports only	Exit annuity $100 per year only
				Number		
Steps to equilibrium	Technological	50	54	48	57	47
	Structural	60	67	57	70	56
Number of firms	Initial	100	100	100	100	100
	Maximum	113	113	112	114	113
	Final	78	78	76	81	73
New technology firms	Maximum	89	92	86	96	83
	Exits	12	14	10	15	10
				Dollars		
Net farm income	Initial	63,000	62,882	62,801	63,079	63,000
	Minimum	38,227	39,617	36,469	42,007	42,682
	Final	47,643	47,911	46,346	48,871	52,433
Landlord payments	Initial	7,000	7,163	7,168	6,997	7,000
	Maximum	14,239	17,877	17,256	15,807	13,103
	Final	11,680	13,591	13,304	12,478	10,230
Output price	Initial	1.000	1.000	0.999	1.001	1.000
	Minimum	.620	.695	.648	.685	.648
	Final	.730	.762	.748	.746	.775
				Units		
Output produced	Initial	100,000	100,069	100,057	100,013	100,000
	Maximum	141,751	146,992	138,766	150,213	138,759
	Final	129,736	130,674	127,774	113,912	124,704
				Dollars		
Government cost	Initial	0	245	145	100	0
	Maximum	0	13,977	7,195	10,668	4,000
	Final	0	5,524	2,324	4,414	4,000
Parity income payment	Maximum/farm	0	0	0	[illegible]	0
				Units		
Government commodity purchases	Maximum	0	13,389	0	15,572	0
	Final	0	4,527	0	5,920	0
				Acres		
Government acreage diversion	Maximum	0	31.8	48.4	0	0
	Final	0	17.3	19.7	0	0
Acreage harvested	Initial	100.0	98.6	98.6	99.8	100.0
	Extremum	113.8	83.5	67.1	114.8	112.7
	Final	111.1	95.9	93.2	112.1	108.9
				Units		
Output per acre (sector)	Maximum	1,251.1	1,760.2	2,069.0	1,319.5	1,232.6
	Final	1,167.4	1,362.1	1,370.8	1,194.7	1,145.2
Output per acre (innovators)	Maximum	2,045.9	2,419.6	2,849.8	2,046.3	2,045.9
	Final	1,167.4	1,362.1	1,370.8	1,194.7	1,145.2
				Response		
Supply elasticity	Initial	.217	.216	.216	.217	.217
	Maximum	.654	.538	.620	.675	.559
	Final	.476	.476	.449	.491	.410

The adjustments to the new technology, given this more-elastic demand, were studied in the presence of four program options and the free market (app. table 2). The options included price support, acreage diversion, the $100 exit annuity, and a combined price support acreage diversion option. With the more-elastic demand structure, prices did not decline as rapidly, output could expand more, profits did not decline as much, and landlord payments are higher than in the base case. More firms are attracted into the industry, more remain in the final equilibrium, and the equilibrating process takes more time. The peak number of new-tech firms increases and the number of new-tech firms which exit increases, compared with the simulations with lower demand elasticity.

The more elastic demand function reduces the government program expenditure. Peak levels of expenditure under the price support and the price support-acreage diversion programs are 58 percent of their levels given the inelastic demand, and expenditures for the acreage diversion program are half that under the inelastic demand. Expenditure on the exit annuity is only slightly less than in the base case, since only two fewer exits occur under the elastic demand than under the inelastic case. The steady-state costs of the price support and acreage diversion options are similarly reduced. With the more-elastic demand structure, the exit annuity costs nearly as much as the price support program in the steady-state and more than the pure acreage diversion program.

Cobb-Douglas production function: The quadratic production function used in the main text was chosen because it could represent concavity and possess both positive and negative price responses of input demand, as well as demonstrate both negative and positive input responses to product price, while maintaining a positive supply response to product price. The quadratic function is neither homogeneous nor homothetic. The Cobb-Douglas function is often used by economists and is homogeneous and homothetic, but does not demonstrate the other properties of market response.

The Cobb-Douglas (C-D) production functions were calibrated so that each would reproduce the initial equilibrium levels at the original prices of inputs and output. Under the old technology, the production elasticities were 0.20, 0.10, and 0.07 for labor, fertilizer, and land. Under the new technology, the production elasticities were 0.022, 0.192, and 0.034. The "intercepts" of the production functions were 1,000 for the old technology and 1,569.4 for the new technology. The price elasticity of supply is 0.587 for old-technology firms and 0.331 for new-tech firms. The elasticity of input demand with respect to output price is 1.587 for old-tech firms and 1.331 for new-tech firms, with the same elasticity pertaining to all three inputs.

The most significant difference in response from the base run is the reduction in the acreage demand, and fall in the land rental rates, as the new technology becomes adopted in the industry. The new equilibrium acreage level was a harvest of 58.8 acres, at a rental rate of $40 per acre, compared with the harvest of 104.3 and rent of $79 under the comparable equilibrium based on the quadratic function and the initial harvest of 100 acres at a rent of $70 in the initial equilibrium. Landlord payments fell to $1,836.9 from an initial $7,000, before recovering to a $2,353.5 level, compared with the rise to $10,857 and equilibrium at $8,241 under the comparable simulation with the quadratic functions.

The Cobb-Douglas version of the model required more time to equilibrate (52 periods vs. 43), attracted more entrants into the industry (12 vs. 7), and had more firms in the final equilibrium (71 vs. 65). The maximum number of new-tech firms was 80 with the C-D technology, compared with 71 under the quadratic, and 9 C-D firms exited after adopting the new technology vs. 6 quadratic firms.

In constrast with the desired parameters built into the quadratic response, the Cobb-Douglas response was constrained. All cross-price elasticities of input demand were constrained by the C-D to be negative, rather than either sign under the quadratic. Expansion paths under the C-D were linear rays emanating from the origin, rather than nonlinear curves which could approach the origin under the quadratic. The constant factor shares under the C-D limited the potential range of adjustments within the firms, and consequently in the markets for those inputs. Consequently, the divergence between the adjustment paths under the C-D from those under the quadratic should not be surprising.

Alternative quadratic production function: An alternative quadratic production function was developed around the input demand elasticities estimated by Binswanger. Binswanger's own-price elasticities were -0.91 for labor, -0.95 for fertilizer, and -0.34 for land. Because his methodology did not estimate output-price elasticities, a set of values was specified which contrasted with the previous assumptions. The elasticity of labor demand was set at +1.0, the fertilizer demand elasticity at +1.25, and the land demand elasticity at -0.1 with respect to the price of farm output.[47] Given those values, under the old technology the maximum attainable output is 1,159 units, corresponding to input levels of 2.0 units of labor, 2.25 units of fertilizer, and 0.9 units of land. These numerical values would be the intercept of the supply function and the intercepts of the respective input demand functions. The matrix of price response coefficients, H^{-1}, contains the following elements:

-0.0045	-0.00197	+0.001528
-0.00197	-0.0095	+0.001342
+0.001528	+0.001342	-0.00485

Under the new technology, the maximum attainable supply was 2,224.4375, corresponding to 1.9152857 units of labor, 5.187785 units of fertilizer, and 0.950714 units of land. The same matrix of price response coefficients was used to characterize the new technology as did the old. The new technology differed from the old by a linear function of the inputs, with a small shift in the intercept of the production function.

The quadratic production function, given by $F(x) = a + d'x + (1/2)\, x'Hx$, which is consistent with these supply and input demand functions, has the following

---

[47] The rationale behind the choice is this. The previous parameter set contained input demand elasticities which were positive and less than one. All the Cobb-Douglas elasticities were greater than one. The acreage demand elasticity does not have to be positive for the price effect of the technology to overwhelm the input demand shift. The chosen elasticities represent an elastic response, a unitary elasticity, and a "small" negative elasticity of response to the price of the output.

parameters: Under both technologies, $\mathbf{H}$ contains the following elements:

$$
\begin{array}{rrr}
-266.19 & +45.12 & -71.30 \\
+45.12 & -117.19 & -18.20 \\
-71.30 & -18.20 & -233.35
\end{array}
$$

Under the old technology, d' = (495.0, 189.8, 393.6), and under the new technology, d' = (343.5, 538.9, 452.8). Under the old technology, a = 273.32 and under the new technology, a = 282.47.

The starting point for the simulations was 100 firms using the old technology, 0 firms using the new, with input levels (1, 1, 1) and output 1,000 under the old technology. Input price levels were (200, 100, 70) and the output price was $1.00. Net farm income was $63,000 for the entire sector, $630 each for the old technology firms. At those initial price levels, new-tech firms would produce 2,065.4 units of output, using (0.92, 3.94, 1.05) units of input, and would realize a profit of $1,415.

In comparison with the model discussed in the main text, this version required more time to reach equilibrium, was more responsive to the product price, and had a qualitatively different response in the land market (see app. table 3). Harvested acreage initially increased with the spread of the new technology, but as the product price fell the harvested acreage began to decline and equilibrated at levels less than the original harvest. Land rental rates rose for a period and then declined, equilibrating below the initial levels. Landlord compensation, being the product of the rental rate and the harvested acreage (except in the presence of an acreage diversion option), followed a similar pattern. In the main text, the equilibrium levels of harvest, rents, and landlord payments exceeded the original levels.

The higher output-price elasticity of supply moderated the expansion of output resulting from the new technology. The product price decline consequently was less than in the main text, and the industry net income decreased less and equilibrated at higher levels than under the parameters in the main text. The retarded decline in profits delayed the exit of firms and extended the time to the new equilibrium. The slower increase in production reduced the government commodity purchases under the price support options and reduced the acreage under the diversion options. The higher profit levels reduced the direct payment required under the "parity income" program. Except for the exit annuity options, government expenditure is less than that in the main text.

Appendix table 3: Effect of government programs on simulated technological adoption (Binswanger-based production sector)

Variable		No government programs	Price supports and acreage diversion	Acreage diversion only	Price supports only	Price supports, acreage diversion, and parity income payments	Parity income payments only	Exit annuity $100 per year only	Exit annuity $50 per year only
					Number				
Steps to equilibrium	Technological	46	55	44	71	77	70	44	45
	Structural	57	70	52	83	92	82	52	54
Number of firms	Initial	100	100	100	100	100	100	100	100
	Maximum	108	109	107	109	110	109	108	108
	Final	67	71	66	74	71	67	63	65
New technology firms	Maximum	80	88	77	86	86	79	73	76
	Exits	13	17	11	12	15	12	10	11
					Dollars				
Net farm income	Initial	63,000	62,930	62,784	63,143	62,930	63,000	63,000	63,000
	Minimum	33,697	38,066	29,833	43,124	41,012	38,496	37,109	35,455
	Final	41,562	43,124	39,841	44,842	43,124	41,562	45,238	43,306
Landlord payments	Initial	7,000	7,272	7,277	6,992	7,272	7,000	7,000	7,000
	Maximum	8,884	15,424	18,446	9,925	16,117	9,170	8,706	8,777
	Final	4,871	8,678	8,481	5,975	8,678	4,871	4,265	4,563
Output price	Initial	1.000	1.001	1.000	1.002	1.001	1.000	1.000	1.000
	Minimum	.547	.668	.603	.660	.663	.552	.590	.571
	Final	.688	.726	.701	.711	.726	.688	.750	.715
					Units				
Output produced	Initial	100,000	100,043	100,003	100,039	100,042	100,000	100,000	100,000
	Maximum	118,100	133,798	115,886	136,786	135,552	117,937	116,381	117,172
	Final	112,481	119,042	111,952	121,846	119,042	112,481	110,170	111,384
					Dollars				
Government cost	Initial	0	243	146	99	243	0	0	0
	Maximum	0	19,129	11,520	15,312	28,846	11,249	4,500	2,150
	Final	0	7,837	2,417	7,297	7,837	0	4,500	2,150
Parity income payment	Maximum/farm	0	0	0	0	77.7	105.1	0	0
					Units				
Government commodity purchases	Maximum	0	20,512	0	23,194	22,082	0	0	0
	Final	0	8,084	0	10,260	8,084	0	0	0
					Acres				
Government acreage diversion	Maximum	0	40.3	72.5	0	42.1	0	0	0
	Final	0	23.9	29.9	0	23.9	0	0	0
Acreage harvested	Initial	100.0	99.1	99.1	100.0	99.1	100.0	100.0	100.0
	Extremum	106.0	74.2	43.6	108.3	72.9	106.7	105.6	105.8
	Final	88.0	81.6	75.1	95.1	81.6	88.0	82.9	85.6
					Units				
Output per acre (sector)	Maximum	1,278.1	1,803.6	2,657.9	1,280.3	1,859.3	1,278.1	1,328.3	1,301.9
	Final	1,278.1	1,459.1	1,491.1	1,280.3	1,459.1	1,278.1	1,328.3	1,301.9
Output per acre (innovators)	Maximum	1,965.7	2,405.1	3,395.5	1,966.2	2,467.5	1,965.7	1,965.7	1,965.7
	Final	1,278.1	1,459.1	1,491.1	1,280.3	1,459.1	1,278.1	1,328.3	1,301.9
					Response				
Supply elasticity	Initial	0.318	0.317	0.318	0.317	0.317	0.318	0.318	0.318
	Maximum	1.036	.972	.985	.896	.934	1.028	.864	.934
	Final	.650	.653	.623	.703	.653	.650	.545	.596

Equation Listing

The model was developed using the TK!SOLVER (c) modeling software. TK!SOLVER was developed by Software Arts, Inc., to simultaneously solve mathematical problems by processing the equations in their natural form. The computer program accepts models formulated as algebraic or other equations and values of any of the variables in the model, and then calculates values for unknowns iteratively, or directly, depending on the complexity of the structure. This appendix contains a listing of the "Rule Sheet" and the "Variable Sheet" from the TK!SOLVER model.

The "rule sheet" contains the mathematical equations in the model. The equations are grouped into blocks which represent the overall economic environment, the operation of the government programs, the diffusion and structural changes, the aggregation of firm-level quantities, the responses of firms in each technology, and aggregate measures of productivity.

The "variable sheet" defines the mnemonics for the variables in the model. The numerical value in the "input" column of the variable sheet is that value assigned to that parameter of the model. A value in the "output" column indicates that the corresponding variable is determined endogenous to the model. An "L" in the status column indicates that successive values of the variable are stored in a list (data array) for historical presentation.

```
S Rule
- ----
  "                         Overall economic environment
  "Hired farm employment= 1/2 farm employment = 1/3 US empl = 1/2 labor capacit
  "    labor supply elasticity to farm sector is + 22
  x1=labcap + labbw2 /w1^2
  "                     Fertilizer supply elasticity = 2.0
  x2=fertcap + fertbw2/w2^2
  "  Land supply elasticity = + .4   Unused capacity is 20 % of harvested area
  x3=landcap + landbw2/w3^2
  "          Product demand elasticity -0.4
  y=d1+d2p*p + gd
  consurp=.5*(-d1/d2p - p)*(y - gd)
  "        Government programs   -- price support & acreage diversion
  gd= a*exp(b*(p - ps))
  psp= p*gd
  gad= aa*exp(ba*(p - ps))
  adp= w3*gad
  pay=max(0,lvstd-lprofa)
  direct= nf * pay
  lshake=element('shake,element()-1,0)
  shake= auhs* (step(bestopp+auhs, lprofn) + step(nextopp+auhs,lprofn))+lshake
  gexp= psp + adp + direct + shake
  "                              Diffusion block
  nfchg=-step(bestopp+auhs,lprofn)-step(nextopp+auhs,lprofn)+step(lprofn,entry)
  nf=element('nf,element()-1,icnf) + nfchg
  nchg=step(lprofn, lprofo) + step(lprofn,entry) +step(accel,lprofo)
  n= element('ni,element()-1,-1) + nchg
  ni= n + 0/step(nf,n)
  nt= nf - ni  +  0/step(nf,n)
  ni= nf + 0/(1-step(nf,n))
  nt=0  + 0/(1-step(nf,n))
  "             Aggregation of production and input use
  y=nt*yo +ni*yn
  x1=nt*x1o + ni*x1n
  x2=nt*x2o + ni*x2n
  x3=nt*x3o + ni*x3n + gad
  inter= (nt)*so +ni*sn
  quad=.5*(h11*w1^2+h22*w2^2+h33*w3^2)
  xprod= h12*w1*w2 + h13*w1*w3 + h23*w2*w3
  suplast=2*(inter - y)/y
  "            Traditional firms
  yo=so+(quad + xprod)/p^2
  x1o= bo+ (h11*w1 + h12*w2 + h13*w3)/p
  x2o= bo2+(h12*w1 + h22*w2 + h23*w3)/p
  x3o= bo3+ (h13*w1 + h23*w2 + h33*w3)/p
  inputo=(w1*(x1o+1) + w2*x2o +w3*x3o)/p
  profo= p*(yo - inputo) + w1 + pay
  tfpo= yo/inputo
  "            Innovator firms
  yn=sn+ (quad + xprod)/p^2
  x1n= bn+ (h11*w1 + h12*w2 + h13*w3)/p
  x2n= bn2+ (h12*w1 + h22*w2 + h23*w3)/p
  x3n= bn3+ (h13*w1 + h23*w2 + h33*w3)/p
  inputn=(w1*(x1n+1) + w2*x2n +w3*x3n)/p
  profn= p*(yn - inputn) + w1 + pay
  tfpn= yn/inputn
```

```
S Rule
- ----
  "                    Aggregate productivity indicators
  input=(nt)*inputo + ni*inputn
  profit=(nt)*profo + ni*profn
  profa=profit/nf
  tfp= y/(input )
  x3h=x3-gad
  fp1=w1*x1
  fp2=w2*x2
  fp3=w3*x3
  fptot=fp1+fp2+fp3
  lprofo=element('profo,element( )-1,icprof-1)
  lprofn=element('profn,element( )-1,icprof)
  lprofa=element('profa,element( )-1,icprof)
  yld=y/(x3 - gad)
  yldn=yn/x3n
  yldo=yo/x3o
  lprod=y/(x1 + nf)
  lprodn=yn/(x1n + 1)
  lprodo=yo/(x1o + 1)
  finpn= (200*(x1n + 1) + 100*x2n + 70*x3n)
  finpo= (200*(x1o + 1)+ 100*x2o + 70*x3o)
  finput= nt*finpo + ni*finpn
  ftfp= y/(finput )
  ftfpn= yn/(finpn )
  ftfpo= yo/(finpo )
```

St	Input	Name	Output	Unit	Comment
L		y	100000.02	q	output quantity
L		x1	100.00012	q	quantity of input 1 (labor)
L		x2	100.00032	q	quantity of input 2 (fertilizer)
L		x3	100.00009	q	quantity of input 3 (land rental)
L		x3h	100.00009		harvested acreage
L		nf	100		total number of farms
L		ni	0		number of innovating firms
L		nt	100		number of traditional farms
L		p	.99999949	p	price of output
L		w1	200.00001	p	price of input 1 (labor)
L		w2	100.00016	p	price of input 2 (fertilizer)
L		w3	70.000162	p	price of input 3 (land rental)
L		yo	1000.0002		output on traditional farms
L		x1o	1.0000012		labor on traditional farms
L		x2o	1.0000032		fertilizer on traditional farms
L		x3o	1.0000009		land on traditional farms
L		profo	629.99873		profit on traditional farms
L		yn	1950.0782		output on innovator farms
L		x1n	.21897322		labor on innovator farms
L		x2n	3.7393752		fertilizer on innovator farms
L		x3n	.95316493		land on innovator farms
L		profn	1465.6227		profit on innovator farms
L		profit	62999.873		total sector profit
L		profa	629.99873		average profit per farm
L		input	57000.127		total sector input index
L		inputo	570.00127		input index for traditional farms
L		inputn	684.45483		input index for innovators
L		tfp	1.7543824		total factor productivity for sector
L		tfpo	1.7543824		total factor productivity on tradition
L		tfpn	2.8490970		total factor productivity on innovator
L		fptot	37000.096		total factor payments
L		fp1	20000.026		hired labor factor payment
L		fp2	10000.048		fertilizer factor payment
L		fp3	7000.0227		landlords' factor payment
L		consurp	125000.05		consumer surplus for output market
L		yld	999.99928		yield per acre, sector
L		yldn	2045.8980		yield, innovators
L		yldo	999.99928		yield, traditional
L		lprod	499.99980		output per worker, sector
L		lprodn	1599.7712		labor productivity, innovators
L		lprodo	499.99980		labor productivity, traditional
L		finput	57000.063		fixed wt. input index
L		finpn	684.45371		
L		finpo	570.00063		
L		ftfp	1.7543844		fixed wt. multifactor productivity ind
L		ftfpn	2.8491017		
L		ftfpo	1.7543844		

St	Input	Name	Output	Unit	Comment
L		gexp	0		total government expenditure
L		psp	0		price support payments
L		gd	0		government commodity demand
	0	a			Amt. purchased at support price
	-16	b			ratio of elasticity to price
	.9	ps			price support target
L		direct	0		direct payments for parity income
L		pay	0		parity income payment per farm
	0	lvstd			living standard for parity compariso
L		adp	0		acreage diversion payments
L		gad	0		government acreage demand
	0	aa			acreage diverted at support price
	-9	ba			p elasticity / price of output
L		shake	0		government golden handshake payments
	100	auhs			per farm golden handshake
		lshake	0		lagged handshake payments
		lprofo	809		lagged profit, traditional farms
		lprofn	810		lagged profit, new farms
		lprofa	810		lagged profit, industry average
	810	icprof			initial condition, profit per farm
		n	0	no.	number of innovators (before truncatio
	100	icnf			initial conditions, no. of farms
		nfchg	0		change in total farm numbers
		nchg	1		change in number of innovators
	900	entry			threshold above which new farms enter
	600	bestopp			threshhold below which farms drop out,
	450	nextopp			second best opportunity, comparing hig
	300	accel			threshold to accelerate adoption, comp
	140000	d1			product demand intercept (nongovernmen
	-40000	d2p			product demand slope (nongovernment)
	1200	labcap			asymptote, labor supply
	-44000000	labbw2			coefficient, labor wage ^-2, elast=22.
	200	fertcap			asymptote, fertilizer supply
	-1000000	fertbw2			coefficient, fertilizer price^-2, e=2.
	120	landcap			asymptote, land supply
	-98000	landbw2			coefficient, land price ^-2, elast=.4
L		suplast	.21729355		supply elasticity
	1108.647	so			Traditional supply intercept
	1.893861	bo			trad. labor demand intercept
	1.934142	bo2			trad. fert. demand intercept
	.215824	bo3			trad. land demand intercept
	2058.725	sn			New supply intercept
	1.112833	bn			new labor demand intercept
	4.673514	bn2			new fert. demand intercept
	.168988	bn3			new land demand intercept
	-.0055236	h11			)
	-.0103236	h22			)
	-.0131527	h33			) price response coefficients
	-.0016836	h12			)
	.00541756	h13			)
	.00621355	h23			)
		quad	-194.3150		
		xprod	85.668356		
		inter	110864.7		

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